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A. C. TRUE, Director

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THE FLOW OF WATER IN IRRIGATION CHANNELS

By

FRED. C. SCOBEY, Irrigation Engineer

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INTRODUCTION.

Irrigation systems are designed with the object in view of supplying certain quantities of water to the soil. These predetermined quantities of water must be carried in certain definite channels—of earth, wood, concrete, steel, or other material. Very often the same canal will include channels of all the above materials. Obviously channels in the smoother materials will convey water with less retardation than those in rougher ones. In order to proportion correctly the size of the channel in any given material, the extent to which the flow of water will be retarded by the character of the channel and other conditions must be known. Since this knowledge can come only through actually measuring the flow in channels under known conditions, it follows that the greater number of tests there are available the more definite is the information at the service of the engineer designing canals.

NOTE.—This bulletin treats of the subject of flowing water in irrigation channels. It is based on field tests made for the purpose of determining the retardation factor in Kutter's formula under the various conditions found in practice. The data secured are intended to aid in the design and construction of irrigation and similar channels. This publication is offered for use of engineers designing and measuring irrigation, drainage, and power channels, and for courts and attorneys at law interested in cases involving the carrying capacities of open channels.

In all English-speaking and in many other countries open channels are quite generally designed by the use of Kutter's formula. This formula was derived from such tests, but for the most part under other than irrigation conditions and before some of the now more commonly used materials of construction were generally available.

For the purpose of enlarging the number of tests under irrigation conditions, made by comparable methods, the experiments described in the body of this publication were carried out. For the sake of comparison, and where sufficient cases covering certain conditions were not found, recent tests from other sources are included in the summary table (see p. 19) of the results, and brief descriptions are given in the Appendix.

NOMENCLATURE.

Throughout this publication the following symbols will be used to designate the same element:

A.—The mean area of the water cross section throughout the length of reach tested, in square feet.

a.—The area of any particular water cross section, in square feet.

L.—The length of reach tested, in feet.

h.—The fall of the water surface in the reach tested, in feet.

P.—The mean length of the wetted perimeter throughout the reach tested, in feet.

p.—The length of the wetted perimeter at any particular cross section, in feet.

Q.—The mean discharge of the channel during the test, in cubic feet per second.

R.—The mean value of the hydraulic radius throughout the reach tested, equal to $\frac{A}{P}$, in feet.

r.—The value of the hydraulic radius at any particular cross section, equal to $\frac{a}{p}$, in feet.

s.—The hydraulic grade or slope of the water surface, equal to $\frac{h}{L}$, corrected for any change in the mean velocity head, in feet per foot of length in the reach.

V.—The mean velocity of the water throughout the reach tested, in feet per second.

v.—The mean velocity at any particular cross section, in feet per second.

n.—The coefficient of retardation, in Kutter's formula.

C.—The coefficient of retardation, in Chezy's formula.

HISTORICAL.

In 1775, Chezy, a French engineer, advanced the following formula for the flow of water in channels:

$$V = C\sqrt{Rs} \qquad (1)$$

This formula takes account of the fact that the velocity of water flowing in a uniform channel does not increase for each succeeding second of its passage as would be the case if it followed, unhindered, the law of gravity, but that it acquires a certain velocity early in its flow and from that time the velocity remains quite constant so long as the surrounding conditions are not changed. The tendency for the velocity to increase is just counteracted by the various retarding influences.

The coefficient C was supposed to care for all of the various factors affecting the velocity, such as friction between the moving filaments of water and the containing channel, but did not involve the slope and the mean hydraulic radius.

At the present time the Chezy formula is, for the most part, used as a basis for the design of pipes and other closed conduits, while in the formula used for the design of open channels the value of C is elaborated as follows:

$$C=\frac{\frac{1.811}{n}+41.66+\frac{0.00281}{s}}{1+\left\{41.66+\frac{0.00281}{s}\right\}\frac{n}{\sqrt{R}}} \qquad (2)$$

Substituting this value in formula (1) we have Kutter's formula, expressed in English measures:

$$V=\left\{\frac{\frac{1.811}{n}+41.66+\frac{0.00281}{s}}{1+\left[41.66+\frac{0.00281}{s}\right]\frac{n}{\sqrt{R}}}\right\}\sqrt{R\,s} \qquad (3)$$

In this form the formula takes into consideration the influence of hydraulic grade and of the mean hydraulic radius upon the coefficient C and introduces a new variable, *n*, which is supposed to represent all the retarding influences.

In its elaborated form the above formula represents a vast amount of mathematical plotting and deduction by Wilhelm R. Kutter (1818–1888), aided by E. Ganguillet, both engineers in Berne, Switzerland.[1] It was developed in 1869 from the data covering 81 different gaugings of rivers and canals, ranging from channels a few inches in width to the Mississippi River.

In the use of this formula for the design of channels in which to convey water all of the variables are determined by the materials encountered, the location of the channel, and the form chosen with the exception of *n*, the factor representing the retarding influences. There is a wide range of values which may be assigned to this factor, the friction becoming greater in passing from smooth, planed boards through a list of such materials as concrete, masonry, and earth in good condition to channels choked with grass, moss, and detritus.

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[1] E. Ganguillet and W. R. Kutter, translated by Rudolph Hering and John C. Trautwine, jr. A General Formula for the Uniform Flow of Water in Rivers and other Channels. New York, 1907, 2d ed.

NECESSARY FIELD DATA FOR VALUES OF *n*.

The labors of Kutter and his colleague were devoted to the development of a formula from the field experience of other engineers. Taking his formula as a basis, the later authors have made deductions from the tests of their predecessors and such experiments as they themselves conducted.[1]

The tests of any one experimenter have for the most part been confined to one part of the country, and each one has secured the necessary field data by methods differing more or less from those pursued by the others. The hydraulic elements to be determined in the field are, however, essentially the same.

As previously stated, n is the one factor not easily and assuredly determined in office estimates of canal design. Therefore the field data must be secured with a view to solving the equation in Kutter's formula, with the value of n as the desired answer.

For the sake of brevity in computation, in formula 3, on page 3, let $B = k + \frac{m}{s}$, where k is 41.66 and m is 0.00281, and let $e = 1.811$, while C is the Chezy coefficient, equal to $\frac{V}{\sqrt{R\,s}}$.

Then in formula 3, page 3.

$$n = \sqrt{\frac{e\sqrt{R}}{BC} + \frac{1}{4}\left(\frac{C-B}{BC}\right)^2 R} - \frac{1}{2}\left(\frac{C-B}{BC}\right)\sqrt{R} \qquad (4)$$

None of the variables entering the solution of this equation are directly obtained in the field, although computed from field measurements. The mean area, A, and the mean wetted perimeter, P, are matters of office computation. The hydraulic radius, R, equals $\frac{A}{P}$.

In the field the length of reach chosen is divided into several equal parts, the more the better. At the ends of the reach and at the dividing planes of the various parts sufficient soundings are made at measured distances apart, so that the cross-sectional area may be found.

Beginning at one bank of the canal, assume the soundings to be made the same distance apart, x, and calling the soundings d_0, d_1, d_2,

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[1] P. J. Flynn. Irrigation Canals and Other Irrigation Works. San Francisco, 1892.

Samuel Fortier. Conveyance of Water in Irrigation Canals, Flumes, and Pipes. U. S. Geol. Survey, Water-Supply and Irrig. Paper 43 (1901).

C. C. Williams. Notes on the Flow of Water in Irrigation Ditches. Univ. Colo. Studies, 7 (1910), No. 4, p. 237.

U. S. Reclamation Service, Reclamation Rec., 4 (1913), No. 7.

V. M. Cone, R. E. Trimble, and P. S. Jones. Frictional Resistance in Artificial Waterways. Colorado Sta. Bul. 194 (1914).

J. B. Lippincott. Observations to Determine the Value of C and *n* as Used in the Kutter Formula. Engin. News, 57 (1907), No. 23, p. 612.

. . . . . . d_N, then the area at that particular cross section is expressed as follows:

$$a = N x \left(\frac{d0 + 2d_1 + 2d_2 \;.\;.\;.\;.\;.\;.\; 2d_{N-1} + d_N}{2N} \right) \tag{5}$$

Note that the end soundings are given but one-half the weight assigned to the interior soundings, for the reason that their influence, in considering the average, extends over but half the distance covered by the interior soundings. A similar reasoning applies to the two following formulas.

Assuming the reach of canal tested to be divided into M equal sections and the areas a_o, a_1, a_2, ... a_M found as by formula 5, then the mean area of the water cross section throughout the reach is as follows:

$$A = \frac{a0 + 2a_1 + 2a_2 + \;.\;.\;.\;.\;.\;.\; 2a_{M-1} + a_M}{2M} \tag{6}$$

The lengths of the wetted perimeters at a_o, a_1, a_2, etc., are found either by computation or by plotting each cross section on a large scale and measuring the length by scale of the line of contact between the water and the containing channel. Letting p_o, p_1, p_2, ... p_M be the lengths of the various wetted perimeters for the corresponding areas a_o, a_1, ... a_M, then

$$P = \frac{p0 + 2p_1 + 2p_2 + \;.\;.\;.\;.\;.\;.\; 2p_{M-1} + p_M}{2M} \tag{7}$$

and, by definition

$$R = \frac{A}{P} \tag{8}$$

Thus the field data for the determination of the term R in formula 8 consist of soundings or their equivalent with attendant horizontal measurements to determine the mean values of A and P throughout the reach tested.

The hydraulic grade is taken as the slope of the water surface in the reach of canal tested, corrected for any appreciable change in the mean velocity of the water at the two ends of the reach. If the cross sections develop the fact that the mean velocity at the upper end of the reach is less than that at the lower end, then the difference between the velocity heads necessary to create the velocities at the two ends of the reach must be deducted from the actual fall of the water surface in the reach tested. If the velocity at the lower end is less than that at the upper end, then the lost velocity head, in addition to the surface fall, has been used to overcome the retarding influences.

The general equation for the slope, including this correction is

$$s=\frac{h-(h_{v2}-h_{v1})}{L} \tag{9}$$

where h_{v2} equals the velocity head, in feet, necessary to create the mean velocity at the lower end of the reach, and h_{v1} equals the velocity head of the mean velocity at the upper end of the reach, while s, h, and L have the same significance as shown on page 2. For example, involving this correction see page 15.

In addition to the cross sections spoken of above, the field data necessary to determine the hydraulic grade is an accurate determination of the length of the reach, L, in feet and of the difference in elevation, or fall, h, in the surface of the water between the upper and the lower ends of the reach, in feet.

By far the greatest opportunity for error lies in the determination of the fall. In order to obviate inaccuracies due to slight local changes of surface slope a reach should be chosen of sufficient length that a fair average surface slope may be determined, yet it should not be so long that distinct changes in grade may greatly change the mean velocity throughout the reach. In the experiments conducted by the writer and his associates 1,000 feet was assumed as a fair length to be tested. It is impracticable to make an extended series of measurements and install the equipment necessary to carry a water level through pipes between the two ends of the reach, therefore, whatever method is used for the actual determination of the level of the water surface at the ends of the reach, the difference in elevation between the bench marks at the ends must be determined with a spirit level.

The error will approximate a constant quantity for a given length. Assume an allowable error in feet for careful work of $0.017\sqrt{\text{distance in miles.}}$[1] For length of reach of 1,000 feet the allowable error would thus be 0.0074 feet. A grade of 0.0074 per 1,000 feet would be 0.04 foot per mile. The allowable error for a reach 1,000 feet long would thus be 4 per cent of the grade of a canal having a fall of 1 foot per mile. The error in the determination of the surface slope thus has a great deal more influence on the value of *n* for low gradients (used in connection with large canals in earth sections) than it does for the steep gradients commonly used for irrigation canals.

The value of V, the velocity, in feet per second, is found by the formula

$$V=\frac{Q}{A} \tag{10}$$

The discharge, Q, in cubic feet per second, is determined by a direct measurement in the field, by weir or current meter. The discharge, of course, remains the same throughout the reach tested, but as a rule the mean area, A, is not identical with the area at the place where the discharge was measured, so V will not necessarily be the same as the mean velocity at the section where the discharge was measured.

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[1] Precise Leveling. *In* Topographic Instructions of the U. S. Geological Survey, 1913, p. 100.

The other field data to be taken in order to make the resulting value of n fully comprehensible is a careful description of the material forming the containing channel, including such growths as affect the flow of the water and a description of the influence of all structures in the canal and all changes in alignment throughout the reach tested. This general description should not only cover just the reach tested, but should extend up and down stream for sufficient distances to cover anything influencing the flow within the reach.

Temperatures of the air and water may be taken, but it is doubtful if any deductions may be made as to the direct influence of the various temperatures on the flow of water in the usual more or less irregular channel.

SCOPE OF EXPERIMENTS.

Tests were made on channels in Nebraska, Colorado, Utah, Idaho, Oregon, Montana, California, Arizona, Texas, and Louisiana. These channels ranged in size from small ditches carrying less than 1 second-foot up to canals carrying over 2,600 second-feet. The containing materials of these channels comprise wood, concrete, earth, rubble masonry, cobblestones, and a few special combinations. The velocities encountered extend up to about 10 feet per second. From other sources the writer has obtained the data for additional tests, where in his opinion there was not sufficient evidence in our own experiments from which to draw conclusions. This is particularly true of steel flumes, as none of these visited by members of this force was carrying water at the time. The data covering very high velocities, such as are found in chutes, also came from outside sources. In several cases it was possible to get data covering several tests on exactly the same reach of channel, with varying discharges of water, with a view to proving or disproving the theories of some writers who have contended that the value of n diminishes as the discharge increases, in proportion to some function of the latter, such as the velocity, the hydraulic radius, or the square root thereof.

EQUIPMENT AND METHODS EMPLOYED FOR COLLECTING FIELD DATA.

In order to weigh correctly any new data advanced which tend either to corroborate or to change existing elements in a standard formula it is necessary to know in detail the instruments employed and the methods of taking field measurements. Consequently, the equipment used and the steps pursued in developing the values of n for irrigation canals for various conditions are discussed in some detail in the following paper. The equipment and the methods described were those used by the writer and his assistant, Mr. Ernest C. Fortier. Where those used by his associates were essentially different, the fact is mentioned.

EQUIPMENT.

Tapes.—Linear measurements for length of canal tested were made with a high-grade steel tape, 100 feet long, graduated to tenths of a foot. This tape was also used to determine widths for current-meter measurements for canals more than 25 feet wide and cross-section data for canals more than 50 feet wide. For canals under 25 feet in width the measurements of widths in determining the discharge were made with a small steel tape, 25 feet long, graduated to hundredths of a foot. For taking cross sections on canals less than 50 feet in width a 50-foot cloth tape containing strands of wire was used.

Level.—The writer used a new 18-inch Berger engineer's wye level, equipped with a bubble whose sensibility was rated at 10 seconds of arc for 1 division of scale equal to one-tenth of an inch. The bubble vial was 6.5 inches long. The telescope power was 35 diameters.

Rod.—A new Philadelphia rod, equipped with rod level and with vernier reading to thousandths of a foot was used in the determination of the fall between the bench marks at the upper and lower ends of the reach tested.

Current meters.—Two new small Price cup current meters were used. They were identical in construction, of the combination type; that is, each meter was so equipped that a single or a penta head could be used. The single head records each revolution of the meter and is adapted to water flowing up to about 5 feet per second. The penta head records each fifth revolution of the turbine and is used in high velocities. Both of these meters were rated on both rod and cable by the United States Bureau of Standards at Chevy Chase Lake, Md. They were carefully rated, as it was understood that they would be used for research work. One of these meters was used constantly, throughout the summer, the other one being very carefully cared for and rated against the one in constant use at intervals throughout the summer, so that any variation of the rating curve could be detected early. At the end of the season the one in use was again rated by the writer, at Calexico, Cal., and it was found that if any change had taken place it was too small to necessitate a change in the table.

The meters could be used on either rod or cable. Eight 1-foot sections of rod, graduated to tenths of a foot, were carried.

When the meter was used on a cable the lower 18 inches of cable was replaced with a section of strong piano wire, with a swivel harness-snap connection to the hanger rod attached to the meter.

Two 6-pound lead torpedo weights were carried, while it was found necessary to use 24 pounds of lead in the New York Canal, with velocities up to 6.6 feet per second in depths of 6.62 feet.

On the work done by the writer and S. T. Harding, wherever the meter was used on a rod the latter rested on a foot piece which in turn rested on the bottom of the channel. For use in wooden flumes a small 4-pronged plug was made to screw up into the rod and project out below the foot piece about 0.01 foot. This was easily forced down into the soft pine or redwood composing the floor and prevented the foot from skidding out beneath the meter under the pressure of water. A guy wire made of piano wire was used in high velocities, whether the meter was held on a cable or on a rod. This guy was equipped with a turnbuckle so that it could be adjusted in length and would hold the meter so that the latter took a position in the vertical plane through the front edge of the gauging bridge.

Meter stations.—As it was desirable to measure the discharge in canals near the reaches to be tested for the value of *n*, it was necessary to provide some form of footbridge for small canals and a cable station for canals of such widths that a temporary footbridge was impracticable. For small canals a piece of clear Oregon pine, 2 inches by 8 inches, 16 feet long, was found to make the best bridge. It would span a ditch about 14 feet wide without bending appreciably under the weight of one man. In a few cases standard wading methods were used. Where ditches were slightly wider than this and quite shallow a light tower of wire-trussed 2 by 2 pieces carried the end of the plank out over the water while measurements were made in the verticals between the bank and about 3 feet from the tower. The plank was then changed to the other side of the canal and the tower placed in the portion of the canal previously measured, and the meter measurements in the verticals resumed. Thus at no time did the meter approach closer than about 3 feet to the tower, and the legs of the latter were so small that but little water was disturbed by their presence. In order to measure canals up to about 90 feet in surface width a portable meter station was provided as follows:

A rating car was constructed like the body of a fiber steamer trunk. The covering had no hinges, but was held by trunk fasteners and twin locks, one on each side. When the cover was off iron arms carrying 6-inch sheave wheels and hinged to each end of the car were raised to a vertical position. Coiled in the bottom of the car was carried 130 feet of high-grade haulage cable, three-eighth inch in diameter. Steel standards, turnbuckles, pins, and all other accessories also were packed in the car during moves from place to place. This equipment assembled into a meter station, as shown in Plates IX and XII.

Hook gauges.—Two gauges of the Boyden type were used for determining the fluctuation in the surface elevation of the water throughout the experiments. They were not as well adapted for determining the exact surface of the water at the ends of the reach in order to measure the fall as was the following arrangement.

Bench marks.—In his experiments in Utah, S. Fortier determined the hydraulic slope of the water surface by leveling between the tops of nails, sharpened at both ends and driven into stakes whose tops were below the surface of the water.[1] After considerable experimentation the writer decided that this general arrangement was better than that involving a line of levels between the ends of the reach and in addition another chance of error in measuring down from the established bench marks to the surface of the water. However, the writer modified Dr. Fortier's plan in the following manner:

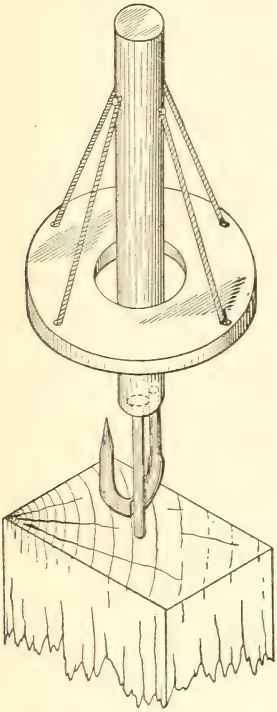

Fig. 1.—Hook device for setting nail head flush with water surface, two-thirds size.

It was found that driving the nail, sharpened at the top as well as at the bottom, dulled the point at the top so that it did not make a good point in order to get a "bead" on the surface of the water in a stilling box, and it also did not make a solid bench mark from which to run levels. A better bench mark would be the ordinary top of a well-made wire nail, but this is not directly adaptable, as it can not be driven to a nicety as a surface gauge. To obviate this feature the device shown in figure 1 was constructed. It consists of a motor-cycle spoke soldered into a hole near the edge of the surface exposed by cutting off a three-eighths inch punch. The spoke was bent in the form of a buttonhook and carefully sharpened. The end of the spoke forming the pointed hook was originally threaded for the nipple, which was retained and served as a protection to the point in carrying the device. The final sharp point is in the same plane as the clean cut end of the punch. Therefore, if the wire nail is driven by means of the punch, in much the same manner as a carpenter sets a nail below the surface of wood with a carpenter's punch, then the top of the wire nail is just flush with the surface of the water when the sharp point of the hook shows at the surface of the water as an ordinary hook gauge. This presupposes that the punch has been held truly vertical in setting the nail. This was assured in the following manner: Near the top of the punch two holes one-sixteenth inch in diameter were bored at right angles to each other. Through these holes a well-oiled fishline formed a four-tie suspension for a perforated disk. The hole in the disk was a trifle larger than the punch which passed through it, so that when held truly vertical the disk acted as a plumb bob, not touching the punch at any point. A very slight leaning of the punch caused the disk to touch, which of course warned the operator that the punch must be plumbed.

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[1] U. S. Geol. Survey, Water-Supply and Irrig. Paper 43 (1901).

In concrete-lined sections and in wooden flumes it was not practicable to use the above device, so a thin headed wire nail was driven horizontally into the side at the water surface. In many cases it was not possible to use a stilling box with such a mark, but it is believed that very little error results where the same operator sets all the marks with the same relation to top and bottom of whatever surface fluctuations exist. Wherever the velocity is sufficient to cause much doubt in the mind of the operator as to the accuracy of the mark, then the total fall between the two ends of the reach tested is so great that any error of a few thousandths is but a very small percentage of the total fall.

Stilling box.—A tin salve box about 3 inches in diameter made a very good stilling box. A hole about three-eighths inch in diameter was made in the center of the bottom. After the nail had been started in the top of the stake in the canal, the box was set over the stake, with the nail projecting through the hole. When the box rested on top of the stake water entered and withdrew slowly and quietly, so that a quiet, definite surface was maintained in the box, and the top of the nail was driven to this surface.

Trimming canal section for measurement.—Where it was necessary to make a current-meter measurement for discharge in a canal and grass or moss was liable to clog the meter and make inaccurate the measurement, or the bottom was slightly uneven, the sides and bottom were neatly trimmed, and all interfering growths removed by means of a sharp short-handled hoe.

FIELD METHODS.

The general method used by the writer in conducting the measurements for the field data was as follows: Minor changes were sometimes necessary for various reasons.

A length or reach of the canal to be tested was chosen. The discharge measurement was started immediately, preferably at the center of the reach chosen. While the measurement was progressing, the length of the reach was carefully chained, the final length being determined by actual position of the two nails driven to the water surface at the ends of the reach. The upstream nail was always set first, so that the party walked downstream with any slight change in volume of the discharge rather than have this change pass them, as it would if the lower nail were set first. Enough cross sections were taken to determine the mean water area and length of wetted perimeter throughout the reach. Nails were set with their tops flush with the water surface at each end of the reach. Levels were then run between these nails as bench marks. Temperatures of air and water were taken. After all these data had been taken the chief of party was familiar enough with the conditions to write an intelligent description covering the features influencing the flow of water throughout the reach tested.

Throughout the descriptive matter in this publication station 0 is at the upper end of the reach, and integral stations represent 100-foot intervals below station 0.

Canal reach.—Actual conditions encountered in the operation of irrigation systems and under which canals must carry water were those desired, as it was believed the designer must take these into consideration in developing the hydraulic elements of his proposed canal. Other things being equal, a reach of canal 1,000 feet long was chosen with quite uniform flow, not only throughout the reach but also up and down stream so far as conditions might influence results. These reaches were chosen on tangents, on curves, and on both, in order to determine the influence of curves on the retardation factor.

Discharge measurements.—Small discharges were, when practicable, measured with a Cipolletti weir, under standard conditions. Discharges of more than 4 second-feet were measured with the current meter. The surface widths of ditches less than 10 feet in width were divided by vertical lines one-half foot apart. Those of canals more than 10 feet in width were divided into approximately 20 verticals, the sections thus formed near the banks being narrower than those toward the middle, for the reason that the velocity changes more rapidly near the banks. The average velocity in the verticals was determined, as a rule, by the multiple-point method, interpreted through vertical velocity curves. In any one vertical the meter was held at points 0.2, 0.4, 0.6, and 0.8 of the total depth below the surface of the water. In addition to these points, at approximately every other vertical, the meter was held at points 0.1 or 0.2 foot (depending on the surface velocity and consequent roughness) below the surface, and just clearing the bottom. These points gave the necessary information to plat correctly the vertical velocity curves between the surface of the water and the point 0.2 of the depth below the surface and between the bottom of the channel and the point 0.8 of the depth below the surface. In addition to all of these points, in many verticals the meter was held at a point 0.3 of the depth below the surface for the purpose of developing the point representing approximately the maximum velocity in the vertical. The velocity at this point does not always correctly represent the maximum, since in in various verticals taken throughout the summer, in many kinds of channels, the maximum was found at points varying all the way from 0.2 depth to 0.8 depth. These statements refer, of course, to velocities found by holding the meter at these particular fractions of the depths. A close study of any one vertical might show that the maximum velocity occurred at some place between these points, but that phase was immaterial to the studies covered in this publication. The necessary corrections were applied to the velocities indicated near the bottom and surface, on account of the fact that the cup current meter does not run true to standard rating curve when held nearer the surface than 0.3 of a foot and when held near the bottom.[1]

The particular points at which to hold the meter were chosen with a view to determining the variations from the discharge of water found in this way that would be found if shorter and more generally used commercial methods of meter gauging had been employed. The various points at which the current meter was to be held were determined as follows: After the tape had been stretched across the canal at the section where the measurement was to be made a bench mark was set at the surface of the water near one bank. The depths at the various verticals were determined by taking with the level the difference in the rod readings between the rod held on the bench mark at the water surface and the rod held at the bottom of the channel. This method is better than using a graduated sounding rod, for the reason that all error due to water climbing the rod is eliminated. This method may be used in high velocities through the main portion of the channel for the reason that a nail can always be set near the bank, where the velocity is much lower than near the center. Where the conditions were such that the meter was to be used on a cable, then the desired points at which to operate it in any vertical were found by multiplying the depth of the vertical by 0.2, 0.4, 0.6, and 0.8 and holding the meter the resulting distances below the surface. Where the meter was to be used on a rod, since the bottom of the rod rested on the bottom of the channel for all measurements and the meter is set on the rod while the rod and meter are out of the water, then the distances below the surface of 0.2, 0.4, 0.6, and 0.8 depth become the distances above the bottom of 0.8, 0.6, 0.4, and 0.2, respectively, of the depth, and are so set on the meter rod.

Having taken the soundings and computed the depths in each vertical at which the meter was to be held, the actual meter runs were made. These were as a rule continued at each point for the nearest number of tens of revolutions in a period of about 30 seconds, the actual time to the tenth of a second being taken for 20, 30, or 40 revolutions, or whatever the number might be. This method of operating a meter is better than the old one of running the meter for a given number of seconds, thereby introducing an error due to fractional revolutions.

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[1] For a discussion of this phase of current meter use, see U. S. Dept. Agr., Jour. Agr. Research, 2 (1914), No. 2, p. 77.

Adjustable hook gauge.—At some point within sight of the man operating the meter a small hook gauge was set. Its range was about 0.6 foot with a vernier reading to thousandths of a foot. This gauge was used to determine the rise or fall of the water surface in the canal during the measurement. The final accepted elevation of the water surface was the mean elevation throughout the meter measurement. All soundings for cross section and the final setting of the bench marks from which the hydraulic grade was determined were based on this mean value of the elevation of the water surface.

Hydraulic grade.—Hydraulic grade was determined during the latter part of or after the measurements for discharge. In earthen channels stakes were firmly driven at each end of the reach chosen until the top of the stake was about 0.07 foot below the surface. After the wire nails were carefully set, as described on page 10, a line of levels was run between the bench marks at the ends of the reach. The level was kept in careful adjustment, and in addition all instrumental errors were obviated by equalizing the sights. This line of levels was as a rule determined by one sight in each direction. A clear-cut target was set very carefully, and the vernier read by both levelman and rodman, independently. Numerous tests showed that the differences obtained in the total fall between the ends of a reach were well within the allowable error for careful leveling.

Data from which to determine the average value of the hydraulic mean depth, comprising sufficient cross sections taken throughout the length of the reach tested, were taken as a rule by means of a tape and level readings on a rod held at the bottom of the channel at sufficient verticals to give true values of the area and the wetted perimeter. It was obviously impossible to drive stakes and set nails vertically in the tops thereof in flumes and concrete-lined sections. In these sections wire nails were driven horizontally into the bank at the water surface, the head of the nail forming a knife edge which quite clearly defined the surface of the water. They may be protected by stilling boxes in low velocities, and in high velocities the fall is so great that refinement in levels is neither practicable nor necessary. In concrete linings the ends of the reach were so chosen that they came at expansion joints, where it was not a difficult matter to drive a nail or, in cases where the lining formed an unbroken surface, a small hole was first drilled with a machinist's centering punch and the wire nail set in this hole.

OFFICE EQUIPMENT AND METHODS.

Multiplication, division, and addition were performed on mechanical devices. Areas included within vertical velocity curves were determined with planimeters and checked by arithmetical ordinates. Vertical velocity curves were drawn through platted points by using xylonite parabolas. The wetted perimeters were determined by stepping around cross sections, plotted to such a scale that the length of the perimeter could be read as closely as the measurement in the field would warrant. Checking was done by means of slide rules and plotted curves showing the values of *n* for various other hydraulic elements.

CORRECTION FOR VELOCITY HEADS.

In order to bring out the influence of the correction for the difference in velocity heads when there is a difference in areas at the ends of the reach, a concrete example is given:

Test No. 175, made on the Salt River Valley Canal, Arizona. The various items of the data were as follows:

Example showing correction for change in velocity heads.

Length of reach	feet	900.0
Assumed elevation of water surface at station 0	do	90.000
Elevation of water surface at station 9	do	89.319
Fall in water surface	do	00.681
Area at station 0	square feet	38.610
Area at station 3	do	40.41
Area at station 6	do	45.09
Area at station 9	do	43.35
Discharge, found by current meter	second-feet	131.33
Mean area throughout reach, A	square feet	42.16
Mean velocity throughout reach, V	feet per second	3.115
Mean velocity at station 0	do	3.40
Mean velocity at station 9	do	3.03
Velocity head for velocity at station 0	foot	.1797
Velocity head for velocity at station 9	do	.1427
Difference in velocity heads	do	.0370
This difference added to fall, =00.681+0.0370=	do	.718
Slope, *s*, without correction for velocity heads		.00075667
Slope, *s*, corrected for velocity heads		.00079778
Mean wetted perimeter throughout reach	feet	19.52
Mean hydraulic radius throughout reach	do	2.158

Using the above data and solving equation 4, page 4, the value of 0.0217 is found for *n* if the slope as found by the level, uncorrected for velocity heads, is used. If the corrected slope is used, a value of 0.0223 for *n* is found. The change due to this correction is academic rather than practical for the lower velocities, but in such as are found in some flumes and concrete sections the change is very material and should not be disregarded.

ELEMENTS OF FIELD TESTS TO DETERMINE RETARDATION FACTORS IN KUTTER AND CHEZY FORMULAS.

In the following pages are arranged a table (Table I) showing the hydraulic elements followed by text matter giving brief descriptions of the general conditions obtaining at the canals measured by the writer and his associates during the season of 1913 with a few tests made in the two preceding years. In both the table and descriptions the experiments are arranged in groups according to the material of the containing channel, while the order within each group follows an ascending value of *n*, except where several tests were made on the same reach of canal with various discharges of water, in which case tests on that particular reach are not separated.

EXPLANATORY NOTES ON TABLE I.

Column 1 gives the consecutive numbers, which refer to the order followed in the discussions in the following pages and in the appendix.

The small letter a after the number refers to the appendix.

Previously unpublished experiments by members of the force of this office are discussed in the text, while the essential data secured from other sources are abstracted in the appendix.

Column 2 shows the authority and his experiment number where such was carried. The symbols referring to members of this force are as follows:

B refers to Don H. Bark, irrigation engineer in charge of work for this office in Idaho.

F refers to Burton P. Fleming, of the department of mechanical engineering, State University of Iowa.

G refers to W. B. Gregory, irrigation engineer, head of department of experimental engineering, Tulane University, La.

H refers to Sidney T. Harding, at that time irrigation engineer in charge of work for this office in Montana.

McL refers to Walter W. McLaughlin, at that time irrigation engineer in charge of work for this office in Utah.

S refers to the writer, Fred C. Scobey, irrigation engineer at large, in charge of experiments on the flow of water in channels.

The symbols referring to other sources, most of which are publications, are as follows:

RS refers to the United States Reclamation Service, through whose courtesy we were allowed access to the records of experiments conducted by various members of the service.

JBL refers to J. B. Lippincott.[1]

VMC refers to V. M. Cone, in charge of the work of this office in Colorado.[2]

SF refers to Samuel Fortier, Chief of Irrigation Investigations.[3]

W refers to C. C. Williams, professor of railway engineering, University of Kansas.[4]

Column 3 refers to the classification, showing the relative weight to be given the data, A signifying first-class conditions for experimentation. B and C show second and third class conditions, such as too short a reach, a doubtful method of measuring discharge, proximity of disturbing features in the canal, and so on.

Column 5 shows the general shape of the canal cross section, referred to in figure 2. When considered in connection with columns 6, 7, 8, 9, and 11, an idea of the water section may be secured.

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[1] Tests described in Engin. News, 57 (1907), No. 23, p. 612.

[2] Tests selected from Colorado Sta. Bul. 194 (1914).

[3] Tests selected from U. S. Geol. Survey, Water-Supply and Irrig. Paper 43 (1901).

[4] Tests described in Univ. Colo. Studies, 7 (1910), No. 4, p. 237.

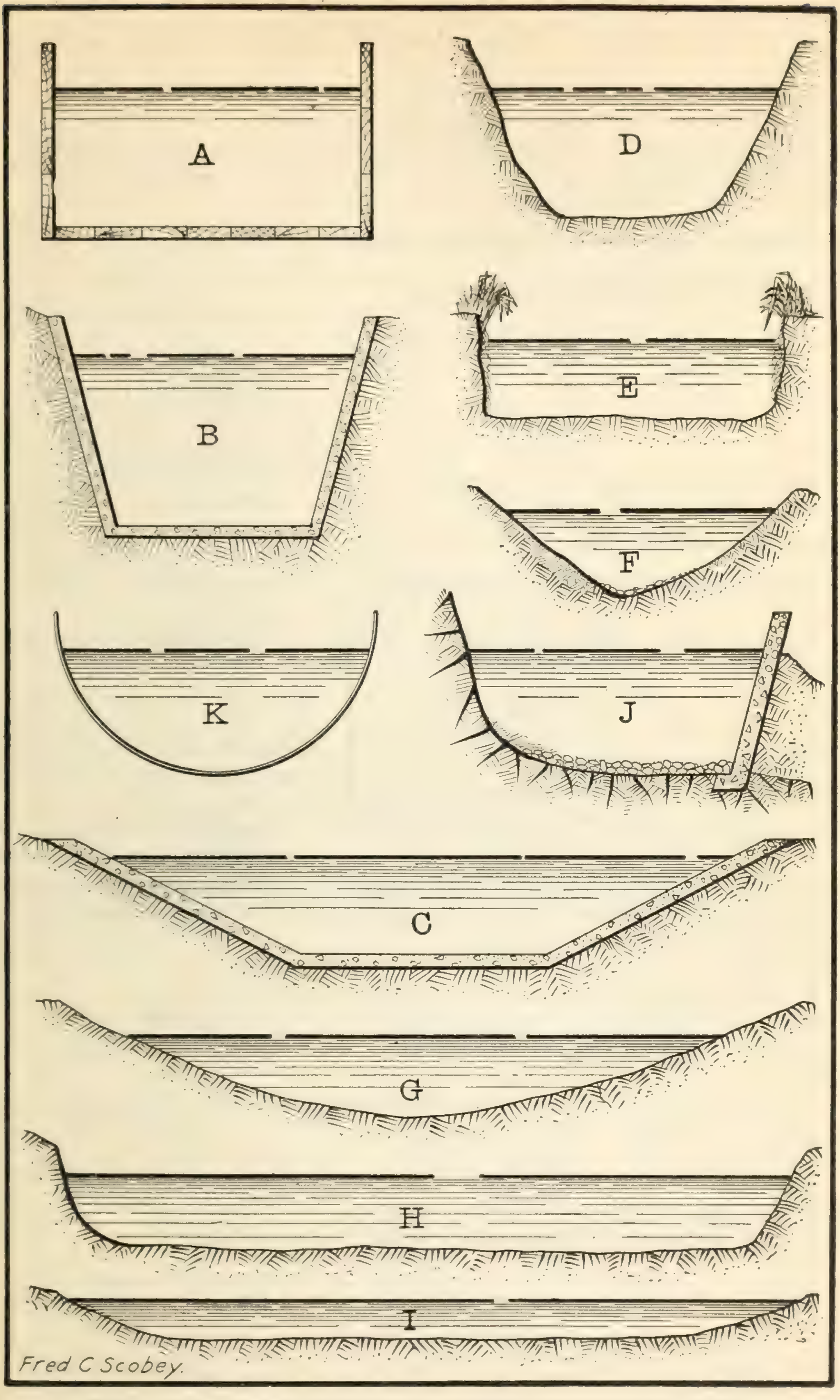

FIG. 2.—Typical shapes of channels used in classifying data in column 5, Table 1.

Column 10 shows the method of securing all depth determinations from which areas and perimeters were secured.

ON refers to office notes. Taken in connection with elevations secured at time of test.

SG refers to a special gauge of some form. Those noted were quite accurate.

LR refers to a difference between level readings on a rod. This obviates all defects of water climbing up the rod, and is the best method, in the opinion of the writer.

S refers to soundings with a graduated stick or rod and although quite accurate in low velocities is uncertain where water climbs up the rod.

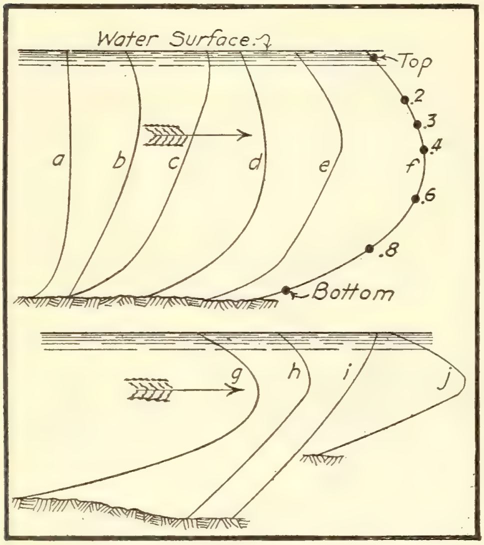

FIG. 3.—Typical vertical velocity curves and depths at which meter was held. See column 15, Table 1.

T refers to measurements by tape on the outside of a flume.

Column 14 shows the method of securing the discharge measurement.

M refers to a current meter.

I signifies the integration method was used. Extensive tests showed that full weight may be accorded this method.

VC signifies that the mean velocity was secured by means of the multiple-point method interpreted through vertical velocity curves.

−2+8 signifies the mean of the velocities obtained at 0.2 and 0.8 depths in each vertical was accepted as the mean of the vertical. Extensive experiments showed this method may be given full weight.

−6 signifies the velocity obtained at 0.6 of the depth below the surface was accepted as the mean for the vertical. Extensive experiments show that the results of this method as a rule are too high and for this reason tests made in this manner are not given full weight.

RC signifies the discharge was taken from a rating curve.

W refers to a weir measurement, under standard conditions.

C after the W signifies that a trapezoidal or Cipolletti weir was used.

Column 15 shows the typical shape of the vertical velocity curves, referred to in figure 3.

Column 23 shows the various wind conditions: C signifies calm; U signifies upstream; D signifies downstream; and A signifies across.

Where of sufficient importance to seriously affect results, additional information is given in the text.

The other columns are considered self-explanatory.

TABLE I.—*Elements of experiments for the determination of retardation factors in Kutter and Chezy formulas.*

1 Reference number.	2 Experimenter.	3 Class.	4 Name and description of channel.	5 Shape of channel.	6 Length of reach tested. L	7 Approximate surface width.	8 Approximate maximum depth.	9 Average depth.	10 Depth determination.	11 Area of water section. A	12 Mean velocity per second. V	13 Discharge per second. Q	14 Discharge determination.	15 Velocity curve.	16 Wetted perimeter. P	17 Hydraulic mean radius. R	18 Hydraulic grade per foot. s	Coefficients of retardation. 19 Kutter. n	Coefficients of retardation. 20 Chezy. C	Temperature. 21 Air (shade).	Temperature. 22 Water.	23 Wind condition.
			Concrete lined.		*Feet.*	*Ft.*	*Ft.*	*Ft.*		*Sq.ft.*	*Feet.*	*Cu.ft.*			*Feet.*	*Ft.*	*Feet.*					
1	S-26	C	New York Canal	C	602.0	59.0	6.6	5.6	ON	332.9	5.48	1,824.00	M-VC	a	63.60	5.23	0.0001611	0.0101	188.7	72	62	C.
2a	RS-14		Main canal, Boise project	C	2,400.0	49.1	2.97			123.5	3.81	469.70	M		50.30	2.45	.0003333	.0130	133.4			
3a	RS-8		do	C	1,000.0	53.7	4.75			219.5	4.68	1,027.37	M		56.5	3.88	.0003875	.0154	120.6			
4a	RS-36		Sulphur Creek wasteway	K	1,300.0		2.3			11.75	20.62	242.00	M		9.03	1.30	.0144	.0108	150.5			
5a	RS-33		Sulphur Creek wasteway, curve.	K	900.0		2.4			12.67	19.13	242.00	M		9.32	1.36	.0206	.0140	114.1			
6a	JBL-6		Los Angeles conduit, curve		700.0					5.16	2.81	14.51	M-2+8		6.22	.83	.00051	.0108	136.7			
7a	JBL-5		do		700.0					5.00	2.71	13.55	M-2+8		6.12	.82	.00051	.0111	132.6			
8a	JBL-2		Tunnel 23, San Gabriel plant	A	318.0	4.5	3.5		SG	15.73	4.74	74.64	M-2+8		11.50	1.37	.00082	.0113	141.6			
9a	VMC		Dry Creek flume, troweled cement.	A	514.5	7.9	1.30		LR	9.76	15.78	154.00	M		10.35	.94	.01459	.0115	134.5			
10a	JBL-1		Tunnel 15, San Gabriel plant	A	446.0	4.5	3.13		SG	14.08	5.01	70.60	M-2+8		10.71	1.31	.00126	.0128	123.3			
11	B-4	A	Ridenbaugh, very smooth	C	1,699.0	22.8	4.30	3.10	LR	70.73	4.15	293.62	M-VC		25.20	2.81	.0002371	.0110	161.5			C.
12	S-24		Ridenbaugh, tangent	C	901.0	22.0	3.80	2.76	LR	60.60	3.65	221.20	M-VC	d	23.90	2.54	.0002508	.0121	144.8	85	64	C.
13	S-24a		Ridenbaugh, tangent and curves.	C	1,819.0	22.0	3.80	2.76	LR	60.50	3.65	221.20	M-VC	d	23.90	2.54	.0002837	.0129	136.1	85	64	C.
14	F-3		do	C	1,020.6	23.6	4.55	3.24	SG	76.59	4.14	316.70	M-VC		26.34	2.91	.000283	.0124				
15a	RS-20		Ridenbaugh, curves	C	2,400.0	15.5	1.65	1.36	LR	20.59	2.45	50.49	M		15.9	1.30	.000329	.0132	118.1			
16a	RS		Lizard chute No. 1, smooth	A	180.0	3.1	.36				15.05	16.42	M			.29	.08244	.0124	97.4			
17a	RS		Lizard chute No. 1, same reach	A	180.0	3.0	.11				6.18	2.04	M			.10	.08244	.0130	67.2			
18a	VMC		Long Pond chute, smooth	A	600.0	4.4	1.53		ON	6.24	19.70	122.94	M		7.24	.86	.02971	.0123	122.4			
19a	VMC		Long Pond chute, same reach	A	600.0	4.4	.71		ON	2.78	12.87	35.79	M		5.68	.49	.02978	.0125	106.6			
20a	RS-5		Umatilla project, smooth	C	932.0					2.76	2.06	5.70	M		4.76	.58	.0007	.013	102.0			
21a	RS-1		Umatilla project, tangent	K	640.0		4.00			28.95	7.10	205.00	M		13.50	2.13	.0014	.0132	129.0			
22a	RS-4		Umatilla project, wavy	K	1,075.0		2.98			28.71	7.15	205.00	M		13.50	2.12	.00177	.0142	119.0			
23a	RS-3		Umatilla project, curve	K	220.0		4.05			29.40	6.94	205.00	M		13.50	2.15	.00273	.0189	90.0			
24a	RS		Arena chute, smooth, straight	B	100.0	6.1	.24				16.38	23.26	M			.22	.02056	.0139	77.2			
25	S-19	B	North Side Twin Falls, Main	A	1,900.0				ON	321.10	8.21	2,637.00	M-VC		59.20	5.43	.0006389	.0138	139.4	73	63	A.
26	F-1		Davis and Weber, medium smooth.	C	552.0	27.8	2.89	2.49	SG	69.29	3.82	364.50	M-VC		29.66	2.34	.000413	.014	125.7			
27	McL	B	do	C				1.75		34.20	3.89	133.30	M-I		23.95	1.50	.000626	.0144	110.0			

TABLE I.—*Elements of experiments for the determination of retardation factors in Kutter and Chezy formulas*—Continued.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Coefficients of retardation.		Temperature.		23
Reference number.	Experimenter.	Class.	Name and description of channel.	Shape of channel.	Length of reach tested. L	Approximate surface width.	Approximate maximum depth.	Average depth.	Depth determination.	Area of water section. A	Mean velocity per second. V	Discharge per second. Q	Discharge determination.	Velocity curve.	Wetted perimeter. P	Hydraulic mean radius. R	Hydraulic grade per foot. s	19 Kutter. n	20 Chezy. C	21 Air (shade).	22 Water.	Wind condition.
			Concrete lined—Continued.		*Feet.*	*Ft.*	*Ft.*	*Ft.*		*Sq. ft.*	*Feet.*	*Cu. ft.*			*Feet.*	*Ft.*	*Feet.*					
28	F-2	....	Davis & Weber, medium smooth.	C	468.5	22.8	1.77	1.59	SG	36.18	3.34	120.90	M-VC	....	24.07	1.50	0.000619	0.0146	109.0	....	....	
29	S-13	A	do	C	1,000.0	23.0	2.60	2.34	LR	53.80	3.94	212.00	M-VC	f	26.00	2.07	.000629	.0154	109.7	85	64	A.
30	B-10	....	King Hill, rough, curves	C	925.0	16.5	....	1.62	LR	21.40	2.55	54.64	M-2+8	....	17.16	1.25	.0004497	.0143	107.5	....	....	C.
31	H-29	A	Hamilton mill flume, new	A	3,000.0	7.0	4.11	4.11	LR	27.90	3.86	107.60	M-VC	....	14.38	1.94	.00062	.0149	111.4	....	....	
32a	VMC	....	South Canal	B	730.0	14.7	1.77	1.71	LR	23.66	4.71	111.30	M	....	16.82	1.41	.00151	.0155	102.1	....	....	
33a	VMC	....	do	B	210.0	10.4	.57	.56	LR	5.78	15.52	89.80	M	....	11.28	.51	.07180	.0158	80.8	....	....	
34a	VMC	....	do	B	142.0	13.3	.45	.40	LR	5.28	11.32	59.68	M	....	13.92	.38	.07230	.0171	68.4	....	....	
35	S-69	A	Sanderfer, smooth, tangent	B	743.3	3.5	1.80	1.43	LR	5.00	3.74	18.71	M-VC	h	5.94	.84	.002375	.0155	92.0	92	70	C.
36a	JBL-8	....	Santa Ana, sand	B	1,000.0	....	....	....	....	10.21	2.62	26.79	M-2+8	....	12.50	.82	.00106	.0157	89.2	....	....	
37	S-37a	A	Lateral 12, Orland project	C	206.0	5.4	.78	.57	LR	3.06	1.86	5.71	M-VC	....	5.67	.54	.00099	.0160	80.2	96	81	C.
38	S-37	A	do	C	755.8	5.4	.80	.62	LR	3.33	1.71	5.71	M-VC	e	5.74	.58	.001184	.0192	65.2	96	81	C.
39a	JBL-7	....	Colton, tangent, moss	....	1,000.0	....	....	....	....	6.75	2.27	15.34	M-2+8	....	6.88	.98	.0007	.0167	87.7	....	....	
40	S-11	A	South Cottonwood Ward, sand	B	350.0	2.6	.90	.80	S	2.07	1.38	2.86	M-I	....	3.98	.52	.000694	.0171	72.6	79	51	C.
41	S-55	A	Modesto main, rocks	B	755.6	21.0	1.55	1.52	LR	32.02	3.58	114.80	M-VC	e	23.22	1.38	.001157	.0174	89.7	106	75	C.
42	S-63	A	Santa Ana main, deposit, sand.	B	1,082.8	11.5	1.58	1.41	LR	16.18	1.67	27.16	M-VC	e	13.25	1.22	.0003208	.0176	84.6	83	76	C.
43	S-70	A	Los Nietos, deposit, sand	B	600.5	4.4	2.15	1.52	S	6.69	2.89	19.36	M-VC	e	6.81	.98	.001444	.0188	76.8	86	76	A.
44	S-67	A	Arroyo Ditch, tangent, moss	B	1,000.0	4.1	1.90	1.60	LR	6.56	2.83	18.54	M-VC	f	6.89	.95	.001449	.0188	76.2	80	82	C.
45	S-31a	A	North Canal, rough, tangent	B	240.0	12.9	2.78	2.58	S	33.38	2.91	98.30	M-VC	e	17.20	1.94	.000525	.0177	92.5	86	62	D.
46	S-31b	A	North Canal, tangent and curve	B	1,013.0	12.9	2.78	2.58	S	32.52	3.02	98.30	M-VC	....	17.10	1.90	.000639	.0187	86.9	86	62	D.
47	S-30a	A	North Canal, tangent	B	240.0	12.7	2.22	2.07	S	26.26	2.85	74.86	M-VC	f	16.15	1.63	.000629	.0176	90.8	78	75	C.
48	S-30b	A	North Canal, tangent and curve	B	1,013.0	12.7	2.22	2.05	S	26.05	2.87	74.86	M-VC	....	16.10	1.62	.000729	.0190	83.5	78	75	C.
49	S-32a	A	North Canal, tangent	B	240.0	12.4	1.10	.99	S	12.25	2.10	25.74	M-VC	h	13.87	.88	.000950	.0192	72.5	80	62	C.
50	S-32b	A	North Canal, tangent and curve	B	1,013.0	12.4	1.10	1.02	S	12.61	2.04	25.74	M-VC	....	13.90	.91	.001021	.0206	67.1	80	62	C.
51	S-38	A	Main, Orland project	C	301.0	21.0	2.20	1.77	LR	37.09	2.27	84.32	M-VC	e	22.75	1.63	.000574	.0211	74.3	98	82	C.
52a	JBL-4	....	Upper, Riverside, two curves	C	600.0	....	....	....	....	6.96	1.22	8.50	M-2+8	....	9.89	.70	.00063	.0218	58.0	....	....	
53	S-68	B	Small ditch, cement wash	B	575.4	2.7	1.70	1.04	S	2.82	1.07	3.02	M-I	....	4.52	.62	.0005839	.0220	56.1	80	70	C.
54	S-75	A	Lower, Riverside, rough broken.	B	699.0	11.0	1.30	1.14	LR	12.57	1.88	23.64	M-VC	....	12.30	1.02	.000851	.0221	63.8	78	73	C.
55	S-71	A	Upper, Riverside, sandy bottom.	B	329.6	12.9	2.20	2.07	LR	26.68	1.79	47.83	M-I	....	16.64	1.60	.000482	.0231	64.4	96	71	C.
56a	JBL-3	....	Upper, Riverside, sand, grass	B	800.0	....	....	....	....	30.92	1.96	60.52	M-2+8	....	20.74	1.49	.00092	.0284	52.9	....	....	

			Wooden flumes.																			
57	S-50	A	Reno, surfaced, battened	A	800.0	9.6	....	5.61	T	56.11	4.49	251.80	M-VC	c	24.60	2.28	.0003108	.0103	169.0	....	....	D.
58	H-30	A	Bitter Root Valley Irrigation Co.	A	500.0	17.7	....	2.51	LR	44.05	3.23	142.10	M-VC	e	22.70	1.94	.00024	.0112	150.0	....	....	
59	B-11	A	King Hill, smooth	A	1,119.0	6.5	....	2.28	....	15.02	5.79	86.99	M	....	10.85	1.35	.001288	.0115	139.2	....	....	
60a	VMC	....	Orchard Mesa Power, surfaced	A	....	12.0	....	2.28	ON	27.54	5.08	139.50	M	....	16.60	1.66	.000713	.0112	149.7	....	....	
61a	VMC	....	do	A	....	12.0	....	1.40	ON	16.77	3.80	63.30	M	....	15.10	1.11	.000710	.0114	136.2	....	....	
62a	VMC	....	do	A	....	12.0	....	2.94	ON	35.21	5.96	209.30	M	....	17.97	1.96	.000965	.0123	138.9	....	....	
63a	VMC	....	do	A	....	12.0	....	3.29	ON	39.45	5.81	228.80	M	....	18.60	2.12	.000858	.0126	137.6	....	....	
64	S-34	A	Central Oregon Irrigation Co., surfaced.	A	1,100.0	16.0	....	2.74	T	43.82	9.12	399.77	M-VC	f	23.10	1.90	.00210	.0117	144.7	76	72	C.
65	H-16b	A	Alkali Creek, waterworn, slime	A	834.0	10.0	....	2.08	LR	20.80	7.80	160.79	M-VC	b	14.15	1.47	.00213	.0118	139.0	....	....	
66	H-16c	A	Alkali Creek, same reach	A	834.0	10.0	....	2.12	LR	21.20	7.30	153.40	M-VC	....	14.24	1.49	.00213	.0126	129.0	....	....	
67	H-16a	A	do	A	834.0	10.0	....	2.61	LR	26.10	7.93	206.88	M-VC	b	15.22	1.72	.00213	.0127	131.0	....	....	
68	H-16d	A	do	A	834.0	10.0	....	1.63	LR	16.30	5.45	88.74	M-VC	d	13.26	1.23	.00213	.0149	106.0	....	....	
69a	RS	....	Fargo drop, plank, tar-coated	A	250.0	6.1	.25	....	....	....	14.31	21.82	....	....	....	.23	.01054	.0122	91.7	....	....	
70	H-39	A	Bitter Root Valley Irrigation Co.	A	700.0	15.8	....	2.53	LR	40.00	2.32	92.80	M-VC	d	20.86	1.92	.00016	.0125	132.5	....	....	
71	H-37	A	do	A	1,000.0	15.7	....	2.33	LR	36.70	2.60	95.50	M-VC	....	20.40	1.80	.000225	.0127	129.5	....	....	
72	H-28	B	Hedge, new, surfaced	A	150.0	9.6	....	2.32	LR	31.90	2.08	66.50	M-VC	....	16.30	1.96	.000133	.0129	129.0	....	....	
73	H-32	....	Bitter Root Valley Irrigation Co.	A	1,000.0	17.7	....	3.00	LR	53.10	2.67	142.10	M-VC	....	23.70	2.24	.00020	.0135	126.0	....	....	
74	H-11	A	Billings Land and Irrigation Co., lateral 4.	A	606.0	2.0	....	.66	S	1.32	1.64	2.16	M-VC	j	3.32	.40	.000868	.0138	88.3	....	....	
75	S-16	A	Telluride flume, surfaced	A	400.0	5.9	....	4.37	T	25.65	6.21	159.34	M-VC	f	14.60	1.66	.00169	.0141	117.1	89	54	C.
76a	SF-23	B	Bear River, surfaced	A	125.0	....	....	....	....	11.78	5.46	64.34	M	....	13.62	.87	.0032	.0142	103.4	....	....	
77	S-35c	A	Arnold, curve and tangent	A	616.0	11.9	....	1.45	LR	17.27	3.71	64.02	M-VC	....	17.45	.99	.001044	.0131	115.5	76	60	C.
78	S-35	A	Arnold, curves and tangents	A	2,200.0	11.9	....	1.57	LR	18.63	3.44	64.02	M-VC	h	17.65	1.06	.001048	.0145	103.5	76	60	C.
79	S-35a	A	Arnold, curve	A	437.0	11.9	....	1.61	LR	19.15	3.34	64.02	M-VC	....	17.70	1.08	.001035	.0150	100.2	76	60	C.
80	S-35b	A	Arnold, tangent	A	1,147.0	11.9	....	1.61	LR	19.19	3.34	64.02	M-VC	....	17.75	1.08	.001054	.0152	98.7	76	60	C.
81a	VMC	....	Oxford, floor transverse	A	1,712.0	9.7	1.42	1.07	S	10.41	1.54	16.01	M	....	7.23	.93	.000274	.150	96.4	....	....	
82	H-22	A	Hedge, old, surfaced	A	750.0	7.8	....	2.85	LR	22.10	3.13	69.07	M-VC	....	13.47	1.64	.00053	.0153	106.0	....	....	
83	H-24	A	do	A	1,000.0	7.6	....	2.79	LR	21.30	3.06	65.20	M-VC	....	13.02	1.62	.00053	.0155	104.5	....	....	
84	S-33b	B	Swalley, tangent and curve	A	159.0	10.0	....	1.23	LR	12.34	4.08	50.31	M-VC	....	13.66	.90	.001934	.0149	97.5	78	61	C.
85	S-33d	A	Swalley, tangent and curves	A	598.0	10.0	....	1.26	LR	12.61	3.99	50.31	M-VC	h	13.63	.93	.002019	.0156	92.9	78	61	C.
86	S-33a	B	Swalley, tangent	A	195.0	10.0	....	1.39	LR	13.92	3.61	50.31	M-VC	....	13.90	1.00	.001479	.0157	93.8	78	61	C.
87	S-33c	B	Swalley, tangent and curve	A	244.0	10.0	....	1.16	LR	11.56	4.35	50.31	M-VC	....	13.30	.87	.002145	.0157	99.3	78	61	C.
88	S-61	B	Golden Rock Lower, rough	A	163.2	5.9	....	.91	LR	5.38	1.30	6.97	M-VC	d	8.20	.66	.0003615	.0159	84.1	74	69	C.
89	S-58	B	Modesto main, asphalted	A	470.0	13.7	....	2.91	LR	39.91	1.08	43.05	M-VC	b	20.55	1.94	.0000568	.0163	97.4	78	72	C.
90	S-6	B	Lateral, Salt Lake City and Jordan.	A	400.0	4.5	....	.80	LR	3.60	6.11	21.96	M-3	....	6.12	.59	.01069	.0167	76.9	80	64	C.
91	S-48	A	Wheeler, battens, worn, sand	A	1,014.4	6.5	....	1.87	T	12.11	1.60	19.35	M-VC	e	11.60	1.04	.0003249	.0167	86.9	74	66	C.
92a	SF-45	....	Elm farm, projecting calking	A	....	....	....	....	....	1.49	.65	.97	W-C	....	4.51	.33	.00038	.0184	57.6	....	....	
93	G-3	....	Roller flume, slimed	A	500.0	13.0	....	2.94	S	55.30	1.22	67.25	M-VC	....	23.00	2.30	.000084	.0191	87.5	74	76	
94	S-76	A	Lower, Riverside, asphalted	A	746.3	7.4	....	.88	LR	6.60	3.58	23.64	M-VC	j	9.21	.72	.003915	.0196	67.6	78	73	C.
95a	SF-8	B	Bear River, rocks on bottom	A	150.0	....	....	....	....	66.60	2.97	197.50	M	....	23.32	2.86	.0004	.0201	87.7	....	....	
96	S-65	A	Fullerton, sand and moss	A	672.1	9.8	....	1.04	LR	10.09	1.56	15.72	M-VC	f	11.75	.86	.0006299	.0202	67.0	91	76	C.
97a	SF-10	B	Bear River, gravel	A	100.0	....	....	....	....	84.05	2.46	207.00	M	....	28.60	2.94	.00031	.0217	81.8	....	....	

TABLE I.—*Elements of experiments for the determination of retardation factors in Kutter and Chezy formulas*—Continued.

1 Reference number.	2 Experimenter.	3 Class.	4 Name and description of channel.	5 Shape of channel.	6 Length of reach tested. L	7 Approximate surface width.	8 Approximate maximum depth.	9 Average depth.	10 Depth determination.	11 Area of water section. A	12 Mean velocity per second. V	13 Discharge per second. Q	14 Discharge determination.	15 Velocity curve.	16 Wetted perimeter. P	17 Hydraulic mean radius. R	18 Hydraulic grade per foot. s	Coefficients of retardation.		Temperature.		23 Wind condition.
																		19 Kutter. n	20 Chezy. C	21 Air (shade).	22 Water.	
			Metal flumes.																			
					Feet.	*Ft.*	*Ft.*	*Ft.*		*Sq. ft.*	*Feet.*	*Cu. ft.*			*Feet.*	*Ft.*	*Feet.*					
98a	VMC	B	Minnesota, smooth, tangent	K	200.0	2.8	.66		S	1.17	6.01	7.04	M		3.13	.37	0.0052	0.0099	136.2			
99a	VMC		Garland, smooth, tangent	K	650.0	5.7	1.11		S	3.66	5.34	19.59	M		6.00	.61	.0023	.0101	142.3		42	
100a	RS		Boise project, smooth	K		2.1	.68				1.66	1.71				.38	.0005	.0106	119.7			
101a	RS		Boise project, smooth, No. 80	K		3.1	.75				2.37	3.36				.41	.00113	.0117	109.9			
102a	RS		Mora Canal, smooth, No. 108	K		3.5	.70				2.55	4.02				.41	.00117	.0112	116.6			
103a	RS		Yarnell lateral, smooth, No. 172	K		2.6	.55				2.88	2.57				.32	.00175	.0122	121.5			
104a	VMC		Garland, smooth, tangent	K	325.0	5.8	1.12		S	4.25	4.40	19.59	M		6.44	.69	.0022	.0126	112.5		42	
105a	RS		Partridge lateral, projecting bands.	K		2.0	.57				1.82	1.39				.32	.00120	.0127	93.6			
106a	RS		Golden Gulch, projecting bands.	K		4.5	1.50				1.43	6.81				.84	.00020	.0129	109.9			
107a	RS		Ten-Mile feeder, projecting bands.	K		5.2	1.65				1.38	8.08				.91	.000175	.013	109.6			
108a	RS		South Ridge, projecting bands	K		2.2	.50				1.68	1.34				.31	.00130	.0139	83.4			
109a	VMC		King lateral, projecting bands.	K	300.5	5.1	2.00		ON	7.32	5.35	39.19	M		6.82	1.07	.00386	.0179	83.1			
110a	VMC		do	K	189.0	5.0	1.68		S	5.77	5.77	33.30	M		6.30	.92	.00537	.0177	82.3			
111a	VMC		do	K	635.0	4.2	1.57		ON	4.65	5.10	23.72	M		5.53	.84	.00411	.0166	86.6		61	
112a	VMC		Stewart, curve, corrugated iron.	K	1,745.0	6.0	1.77			7.67	1.92	14.70	M		7.35	1.04	.000892	.0222	62.8			
			Masonry lined.																			
113	S-29	A	Jacobs, rubble sides	E	225.0	4.2	1.50	1.40	S	5.90	3.82	19.44	M-VC		6.90	.86	.001367	.0130	111.5	88	63	C.
114a	RS		Cottonwood flume, rubble			5.7	1.3				6.17	29.42				.86	.005575	.0163	89.3			
115	S-27	A	Jacobs, unchinked sides	E	280.0	7.4	1.95	1.77	S	13.06	1.49	19.44	M-VC		10.62	1.23	.000471	.0235	61.9	88	63	C.
116	S-28	A	Jacobs, plastered sides	E	280.5	5.1	1.77	1.70	S	8.62	2.26	19.44	M-VC	f	8.21	1.05	.001597	.0250	55.5	88	63	C.
117	S-45	B	Orr, mortar laid	E	213.6	11.5	2.70	2.26	LR	26.02	1.76	45.80	M-VC	f	14.65	1.78	.000636	.0298	52.4	70		C.

Earth channels.

118a	W-14		Interstate, cemented clay							207.50	4.75	830.00			52.10	3.88	.00017	.012	185.0			
119	S-2	B	Farmers', cemented clay	G	1,000.0	51.0	3.70	2.53	S	129.06	2.56	330.00	M-VC	b	53.80	2.40	.000154	.0130	133.0			C.
120	S-1	A	do	G	1,200.0	51.0	3.90	2.74	S	139.81	2.22	310.84	M-VC	b	53.30	2.62	.00017	.0164	105.2			A.
121a	SF-21		Bear River, sediment	G		22.9	3.95	2.70		62.30	3.62	225.55	M		25.00	2.49	.00031	.0134	130.2			
122a	SF-12		Bear River City, sediment	G		11.4	1.22	.90		10.24	1.04	10.68	M		11.85	.86	.00012	.0135	102.2			
123a	SF-15	B	Bear River, Corinne Branch, silt.	G	100.0	23.9	2.80	1.94		4.44	2.36	109.56	M		24.98	1.86	.00027	.0155	105.8			
124a	SF-22		Bear River, Corinne Branch, loam.	G		18.9	2.24	1.67		31.66	2.02	64.02	M		19.78	1.60	.000273	.0164	96.8			
125a	VMC		Fort Lyons, silt, very smooth	I	2,600.0	68.0	1.20	1.13	LR	75.60	1.86	140.55	M		66.80	1.13	.00038	.0165	89.5			
126	S-83	B	Maricopa, hard bed	H	900.0	29.0	3.00	2.31	LR	66.93	1.28	85.51	M-VC		31.50	2.20	.0000804	.0166	99.3	101	80	A.
127	S-3	A	Winter Creek, compact clay	G	800.0	13.5	1.70	1.02	S	13.71	.93	12.77	M-VC		13.90	.99	.0001341	.0170	80.9			D.
128a	W-1b		Empire intake, sand, gravel	H	400.0	48.0	4.00	2.83		135.90	2.94	372.10	M-6		41.70	2.84	.00025	.0170	103.0			
129a	W-1		Empire intake, firm gravel	H	400.0					71.20	2.46	175.50	M-6		41.43	1.73	.00050	.0194	83.6			
130	H-7	A	Billings Land & Irrigation Co., slick loam.	G	1,000.0	24.0	3.80	2.85	S	68.40	2.45	167.56	M-VC	c	26.30	2.60	.000230	.0174	100.0	75	62	
131a	VMC		Jarbeau Power, clay loam	H	900.0	13.6	1.40	1.21	LR	16.43	1.96	32.27	M		14.75	1.11	.00049	.0176	83.8			
132	H-5b	B	Cove, sandy loam, grass	G	600.0	4.5	.75	.53	S	2.37	1.14	2.70	M-VC		5.00	.47	.000617	.0180	66.6	81	65	
133	H-5a	B	do	G	400.0	5.5	.90	.51	S	2.78	.97	2.70	M-VC		5.58	.50	.000460	.0186	64.4	81	65	
134	H-19		Billings Land & Irrigation Co., silted.	H	1,000.0	20.0	2.90	2.32	LR	46.48	2.30	106.93	M-VC	d	21.90	2.12	.000295	.0181	92.0			
135	S-82	A	Grand Canal, hard bed	H	1,000.0	29.0	2.80	1.99	LR	59.57	2.72	161.75	M-VC	e	29.20	2.04	.000438	.0183	90.8	100	84	A.
136a	SF-3		Logan, Hyde Park and Smithfield.	H		13.7	1.60	1.29		17.80	2.58	45.90	M		14.80	1.20	.00083	.0184	81.5			
137	H-18d	B	Billings Land & Irrigation Co., clay, sandy.	H	750.0	25.5	3.00	2.47	LR	63.10	1.46	92.08	M-VC	b	26.90	2.34	.000111	.0186	90.5			D.
138	H-18b	A	Billings Land & Irrigation Co., same reach.	H	750.0	26.5	3.70	2.99	LR	79.20	1.88	148.66	M-VC	d	28.40	2.79	.000152	.0193	91.1			C.
139	H-18a	A	do	H	750.0	27.0	3.80	3.03	LR	81.50	2.10	171.60	M-VC	d	28.70	2.8	.0001867	.0194	91.0			C.
140	H-18c	A	do	H	750.0	26.0	3.60	3.17	LR	82.50	1.67	137.89	M-VC	d	28.90	2.85	.000127	.0199	88.0			A.
141	H-6	A	Billings Land & Irrigation Co., main, clay.		1,000.0	25.0	3.30	2.65	LR	66.2	2.560	169.50	M-VC	d	27.40	2.41	.00033	.0188	90.8	90	60	C.
142	S-87	B	Maxwell, sandy bed	H	600.0	7.0	1.00	.80	S	5.57	.42	2.36	M-VC	d	7.82	.71	.000067	.0192	61.3	76	56	C.
143a	SF-13	C	Bear River, Corinne Branch, clay.	G		4.0	.71	.56		2.23	1.14	2.53	M		4.46	.50	.00068	.0194	61.6			
144a	SF-16	C	Millville and Providence	G	50.0	10.1	1.60	1.14		11.50	1.94	22.28	M		10.80	1.07	.00062	.0195	74.6			
145	H-33	A	Bitter Root Valley Irrigation Co.	H	1,000.0	26.0	3.00	2.33	LR	67.6	1.85	112.50	M-VC	e	27.55	2.20	.000215	.0196	85.3			C.
146a	SF-17	B	Logan and Hyde Park, sand	G	75.0	14.2	2.05	1.53		21.78	1.08	23.55	M		15.60	1.40	.00015	.0197	75.7			
147a	VMC		Mesa lateral (a), sedimented	H	550.0	14.8	2.30	2.20	LR	27.91	1.51	42.16	M		16.52	1.69	.00022	.0200	78.3		70	
148a	SF-20		Solveson & Co., pebbles,	G		7.5	.83	.53		4.00	1.01	4.03	W-C		7.73	.52	.00056	.0201	59.2			
149	S-57	A	Lateral 7, Turlock District, hard.	I	1,000.0	21.0	1.40	1.09	LR	22.96	.67	15.44	M-VC	d	22.10	1.04	.000098	.0202	66.7	84	81	C.
150a	SF-48		Logan City, gravel bed	I		7.2	.18	.14		1.03	.54	.56	W		7.19	.14	.00135	.0204	39.3			
151	H-17	B	Billings Land & Irrigation Co.	H	400.0	24.0	4.00	3.37	S	80.90	2.56	207.00	M-VC		27.40	2.85	.000308	.0204	86.2	67		D.
152a	W-3	C	Rist and Goss, silted	G		6.3	1.00	.57		3.60	.91	3.30	M-6		6.30	.57	.00034	.0204	65.0			
153a	VMC		Willcox, pebbles and rocks	I	400.0	17.1	.80	.51	LR	8.78	1.74	15.29	M		26.30	.33	.00334	.0205	52.1			
154a	W-4	B	Old Barnes, silt coat	G		9.0	1.40	.94		8.50	1.17	9.90	M-6		9.00	.95	.00032	.0206	67.0			
155	H-34	A	Bitter Root Valley Irrigation Co.	H	750.0	26.5	2.88		S	56.40	2.00	112.50	M-VC		27.23	2.03	.000312	.0208	79.5			C.

TABLE I.—*Elements of experiments for the determination of retardation factors in Kutter and Chezy formulas*—Continued.

1 Reference number.	2 Experimenter.	3 Class.	4 Name and description of channel.	5 Shape of channel.	6 Length of reach tested. L	7 Approximate surface width.	8 Approximate maximum depth.	9 Average depth.	10 Depth determination.	11 Area of water section. A	12 Mean velocity per second. V	13 Discharge per second. Q	14 Discharge determination.	15 Velocity curve.	16 Wetted perimeter. P	17 Hydraulic mean radius. R	18 Hydraulic grade per foot. s	Coefficients of retardation.		Temperature.		23 Wind condition.
																		19 Kutter. n	20 Chezy. C	21 Air (shade).	22 Water.	
			Earth channels—Continued.		*Feet.*	*Ft.*	*Ft.*	*Ft.*		*Sq. ft.*	*Feet.*	*Cu. ft.*			*Feet.*	*Ft.*	*Feet.*					
156a	SF-6	B	Logan and Richmond, clay	E	100.0	14.9	2.42	2.15		32.02	2.14	68.56	M		17.80	1.74	0.00046	0.0211	75.6			
157	H-35	A	Bitter Root Valley Irrigation Co.	G	1,000.0	27.0	2.90	2.21	S	59.80	1.59	95.31	M-VC	d.	28.80	2.08	.00020	.0211	78.0			C.
158	H-14	A	Billings Land & Irrigation Co., lateral 2.	G	400.0	8.4	1.40	.98	S	8.20	.78	6.37	M-VC		9.20	.88	.000175	.0212	62.2			D.
159a	SF-4	B	Logan, Hyde Park and Smithfield.	G	60.0	12.0	2.08	1.72		20.61	2.49	51.36	M		13.56	1.52	.00077	.0213	73.0			
160	G-1		Morris, bed ploughed, grassy	I	1,000.0	70.0	4.10	2.98	S	208.50	.43	89.23	M-VC		71.90	2.90	.0000107	.0216	79.6	95	83	A.
161	H-25	A	Hedge, fine granite, few rocks	H	200.0	16.5	2.65	1.94	S	32.00	2.09	67.00	M-VC		17.80	1.80	.00044	.0216	74.4			C.
162	S-78	A	Birch, Imperial Water Co. No. 1, hard bed.	H	1,000.0	10.0	1.60	1.30	LR	13.05	1.34	17.45	M-VC	e.	11.71	1.11	.0003795	.0217	65.0	95	89	C.
163a	SF-11		Point Lookout, sedimented	I		35.8	2.25	1.65		58.94	1.48	87.29	M		36.73	1.60	.00027	.0218	71.2			
164	G-6		Crowley, bed harrowed, grassy	G	1,000.0	27.0	5.10	3.08	S	83.05	.82	68.29	M-VC		27.80	2.99	.0000345	.0219	80.0	89	79	U.
165a	VMC		Bessemer (b), smooth adobe	G	1,600.0	18.2	2.90	2.05	LR	37.27	1.55	57.98	M		19.87	1.88	.00024	.0219	72.9			
166a	VMC		Bessemer (a), smooth adobe	G	1,495.0	16.1	3.50	2.31	LR	37.15	1.56	57.98	M		18.15	2.04	.00036	.0281	57.5			
167	H-8	A	Big Ditch high line, silted	H	1,000.0	10.5	1.70	1.17	S	12.32	1.24	15.22	M-VC	e.	11.65	1.06	.000357	.0220	64.0	98	68	C.
168a	W-2		Louden, clean sand	H		25.0	2.00	1.49		37.30	1.66	62.00	M-6		24.50	1.52	.00038	.0220	69.0			
169a	VMC		Mesa lateral (b), fine silt bed	H	600.0	14.7	2.40	2.00	LR	27.40	1.47	40.32	M		76.46	1.66	.00026	.0220	70.6		70	
170a	VMC		Rio Grande lateral 1 (c), gravel.	I	1,238.0	25.5	1.90	1.46	LR	37.22	3.86	143.60	M		26.20	1.42	.00220	.0221	68.8			
171a	VMC		Rio Grande lateral 1, gravel	I	5,280.0				LR	19.52	1.39	27.16	M		32.80	.60	.00362	.0390	29.9			
172	S-64	A	Santa Ana main, cemented sand.	H	1,000.0	16.5	1.30	1.15	LR	18.92	1.44	27.16	M-VC		17.18	1.06	.000481	.0221	63.6	83	76	C.
173	S-80	A	California Development Co., central main.	H	998.0	38.0	5.00	4.26	S	161.65	2.08	336.91	M-VC	c.	43.80	3.69	.0001682	.0221	83.8	101	86	C.
174	H-20	A	Billings Land & Irrigation Co., gravel.	H	1,500.0	21.5	2.90	2.36	S	50.90	2.00	102.22	M-VC	e.	23.90	2.13	.000335	.0221	75.0			D.
175	S-84	A	Salt River Valley	H	900.0	17.0	3.40	2.48	LR	42.16	3.12	131.33	M-VC	e.	19.55	2.16	.000798	.0222	75.1	100	79	C.
176a	SF-19		Lewiston, clay, moss patches	H		16.6	2.12	1.66		27.53	1.19	32.72	M		18.08	1.52	.00020	.0224	68.1			
177a	W-5	B	Geo. Rist, gravel	H		12.0	1.30	.92		11.00	1.15	12.70	M-6		12.10	.91	.00040	.0224	60.2			
178	H-2	A	Big Ditch, sand bed, mud sides.	G	1,000.0	15.5	3.70	2.43	S	40.10	2.09	83.68	M-VC	f.	18.80	2.13	.000377	.0225	73.7			U.

179	H-38	B	Bitter Root Valley Irrigation Co.	G	400.0	27.0	2.75	2.10	S	56.80	1.63	92.80	M-VC	....	28.85	1.97	.000262	.0226	71.8	....	62	U.
180	S-40	A	Lateral 10, Orland project	G	568.0	12.0	1.75	1.24	LR	14.82	1.78	26.35	M-VC	h	13.20	1.11	.0007365	.0228	62.2	95	....	A.
181a	SF-31		Providence Upper, packed	H		6.5	.63	.51		3.29	.71	2.34	W	....	6.80	.48	.00043	.0229	49.3	....	....	
182a	SF-14		Bear River lateral, silt and moss.	G		5.5	.95	.71		3.89	1.19	4.63	M	....	6.00	.65	.00075	.0230	54.0	....	....	
183a	SF-39	B	Bear River, lateral 2, silt, grass.	I	80.0	7.8	.95	.74		5.74	1.38	7.90	W	....	8.12	.71	.000875	.0230	55.4	....	....	
184	S-39	A	Orland South Main	H	596.1	21.1	2.50	2.12	LR	44.40	1.90	84.32	M-VC	....	23.00	1.93	.0003859	.0231	69.7	98	82	C.
185a	SF-9		Walker tract, loam	G		19.5	2.70	1.96		13.32	1.01	38.55	M	....	20.90	1.83	.00012	.0232	67.8	....	....	
186	S-36	A	River Branch Canal, few cobbles.	H	593.0	16.5	2.40	1.80	S	29.73	2.82	83.86	M-VC	e	17.98	1.65	.001105	.0236	66.0	90	80	C.
187a	SF-1		Providence, medium gravel	H		6.4	.90	.82		5.26	1.90	9.98	M	....	7.40	.71	.00175	.0238	53.8	....	....	
188a	SF-5	C	College and City, gravel, roots.	E	50.0	3.7	.76	.70		2.59	2.93	7.60	M	....	4.73	.55	.00616	.0238	50.4	....	....	
189a	SF-27	B	Logan, Hyde Park and Thatcher.	G	100.0	17.6	2.22	1.74		30.60	1.97	60.23	M	....	18.90	1.62	.0006	.0246	63.2	....	....	
190	G-4	B	Small ditch, new	F	350.0	3.5	1.10	.69	S	2.40	.34	.81	M-6	....	4.15	.58	.0001014	.0246	44.0	69	76	U.
191a	SF-18	B	College and City, uneven	E		4.4	.88	.80		3.51	1.61	5.66	M	....	5.44	.65	.0016	.0247	50.2	....	....	
192	S-88	A	Boulder and White Rock	H	300.0	7.2	.50	.45	LR	3.21	1.00	3.20	M-VC	h	7.54	.43	.001246	.0248	43.3	55	55	
193	H-3	A	Billings Land & Irrigation Co., gravel.	H	1,000.0	28.0	3.90	3.23	S	90.25	1.82	164.45	M-VC	a	31.16	2.89	.000248	.0258	68.2	....	62	D.
194	S-23	A	South Side Twin Falls, lateral.	D	754.0	10.0	2.00	1.49	S	14.88	1.75	26.06	M-VC	e	11.50	1.29	.000737	.0259	56.7	....	....	A.
195	H-1	A	Billings Land & Irrigation Co.	H	1,000.0	27.0	4.25	3.45		93.00	2.35	218.33	M-VC	d	30.80	3.02	.00038	.0259	69.0	90	64	A.
196a	S-F63		Hyrum, rocky, earth bed	H		5.0	.44	.37		1.87	.84	1.57	W	....	5.28	.35	.0013	.0260	38.9	....	....	
197	H-36	A	Bitter Root Valley Irrigation Co.	G	1,000.0	27.0	2.80	2.19	S	59.10	1.61	95.30	M-VC	....	29.00	2.04	.00032	.0260	63.0	....	....	C.
198	S-14	A	North Ogden, gravel	F	800.0	8.5	1.75	1.38	S	11.71	1.72	20.12	M-VC	e	9.77	1.20	.000831	.0262	54.5	66	58	C.
199	S-56	A	Main Branch Turlock district, hardpan.	I	1,000.0	28.0	1.75	1.26	LR	35.24	.99	35.01	M-VC	h	27.80	1.27	.000263	.0262	54.4	93	84	C.
200	H-4	A	Billings Land & Irrigation Co., gravel.	H	1,000.0	24.0	3.50	2.67	S	64.10	2.67	171.34	M-VC	d	26.95	2.38	.00072	.0264	64.2	71	62	D.
201a	VMC		Rocky Ford(a), loose sand bed	H	1,000.0	14.5	2.00	1.69	LR	24.44	1.68	41.20	M	....	16.08	1.52	.00058	.0266	56.5	....	....	
202	S-8	A	Salt Lake City and Jordan	E	600.0	9.5	2.25	2.19	S	20.28	1.57	31.86	M-VC	e	13.21	1.57	.0004783	.0267	57.3	....	62	A.
203a	W-7	B	Loveland and Greeley	I		34.0	2.30	1.74		59.20	1.69	100.00	M-6	....	35.00	1.69	.00050	.0267	58.2	....	....	
204	S-66	A	Fullerton, loose sand bed	G	600.0	12.0	1.50	1.15	LR	13.79	1.14	15.72	M-VC	....	13.38	1.03	.000493	.0269	50.5	91	76	A.
205	S-86	A	Farmers', few rocks	I	600.0	11.0	.90	.61	S	6.76	1.41	9.52	M-VC	h	11.38	.59	.001758	.0270	43.5	82	59	A.
206	H-12a	A	Billings Land & Irrigation Co., sand bed.	G	400.0	8.5	1.80	1.16	S	9.86	1.45	14.28	M-VC	b	9.68	1.02	.000812	.0271	50.6	....	....	
207	H-12c	A	Billings Land & Irrigation Co., same reach.	G	400.0	7.5	1.40	.99	S	7.46	1.23	9.20	RC	....	8.98	.83	.000842	.0277	46.5	....	....	
208	H-12b	B	do	G	400.0	7.0	1.10	.87	S	6.12	1.04	6.37	M-VC	d	8.20	.75	.00082	.0294	42.1	....	....	
209	S-60	A	Yosemite Power Co	H	662.6	3.5	.75	.56	LR	1.95	1.32	2.57	M	....	4.14	.47	.003679	.0274	31.6	64	60	C.
210	S-5	A	Parley's Ditch lateral, sand bed.	F	600.0	5.0	1.20	.74	S	3.70	1.20	4.44	M-2+8	....	5.63	.66	.001168	.0278	43.2	75	54	U.
211a	VMC		Bessemer (b), fine silt, rocks	F	2,002.0	16.4	3.10	2.04	LR	33.56	1.26	42.35	M	....	18.55	1.81	.00028	.0280	55.9	....	....	
212	S-20	C	South Side Twin Falls, lateral.	D	718.0	6.5	1.90	1.25	LR	8.12	2.50	20.32	M-VC	e	8.05	1.01	.002683	.0283	48.1	....	....	C.
213	S-85	B	Arizona Canal lateral	D	700.0	5.5	1.70	1.10	LR	6.09	2.36	14.35	M-I	....	6.66	.91	.003088	.0284	46.0	100	79	A.
214a	VMC		Rio Grande lateral No. 1, gravel.	I	5,280.0	43.7	2.40	1.87	LR	81.62	4.66	380.00	M	....	23.70	1.87	.00366	.0284	56.3	....	....	
215	S-79	A	Beech Imperial Water Co., No. 1, sand bed.	H	1,000.0	8.0	.90	.75	S	5.97	.87	5.18	M-2+8	....	8.67	.69	.000594	.0290	42.8	80	89	C.
216	S-49	A	Wheeler, hard bed, loose rocks.	F	1,164.5	10.5	2.00	1.56	S	16.40	1.18	19.35	M-VC	....	12.05	1.36	.000411	.0292	49.8	78	66	A.

TABLE I.—*Elements of experiments for the determination of retardation factors in Kutter and Chezy formulas*—Continued.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Coefficients of retardation. 19	Coefficients of retardation. 20	Temperature. 21	Temperature. 22	23
Reference number.	Experimenter.	Class.	Name and description of channel.	Shape of channel.	Length of reach tested. L	Approximate surface width.	Approximate maximum depth.	Average depth.	Depth determination.	Area of water section. A	Mean velocity per second. V	Discharge per second. Q	Discharge determination.	Velocity curve.	Wetted perimeter. P	Hydraulic mean radius. R	Hydraulic grade per foot. s	Kutter. n	Chezy. C	Air (shade).	Water.	Wind condition.
			Earth channels—Continued.		*Feet.*	*Ft.*	*Ft.*	*Ft.*		*Sq. ft.*	*Feet.*	*Cu. ft.*			*Feet.*	*Ft.*	*Feet.*					
217a	SF-42		Bear River lateral, clay, irregular.	G		8.4	0.85	0.57		4.79	1.69	8.08	W		8.56	0.56	0.0033	0.0293	39.2			
218a	SF-37		Bear River lateral, similar reach.	G		11.1	1.64	1.15		12.79	.61	7.83	W		11.80	1.08	.00017	.0295	45.1			
219	H-13c	A	Billings Land & Irrigation Co., lateral 1.	F	600.0	11.0	2.00	1.29	S	14.20	.87	12.35	M-VC	d.	12.35	1.15	.00029	.0299	47.8			D.
220	H-13a	A	do	G	400.0	7.5	1.25	.99	S	7.42	1.09	8.08	M-VC		8.95	.83	.00084	.0308	41.3			C.
221	S-59	B	Modesto main, loose sand	I	930.0	55.0	1.60	.86	LR	47.50	.91	43.05	M-VC		54.30	.88	.0005165	.0300	42.7	78	72	C.
222	S-72	A	Upper, Riverside, sand, moss	D	294.9	12.0	2.70	2.30	LR	27.60	1.73	27.83	M-I		14.70	1.88	.000634	.0315	50.2	96	71	C.
223	S-77a	A	Lower, Riverside, tangent	H	355.0	11.5	1.80	1.28	LR	14.78	1.60	23.64	M-VC		12.15	1.22	.0010647	.0318	44.4	78	73	C.
224	S-77b	A	Lower, Riverside, same, with curve.	H	844.4	11.5	1.80	1.50	LR	17.25	1.37	23.64	M-VC		13.05	1.32	.0009095	.0360	39.5	78	73	C.
225a	SF-64		Hyrum, gravel bed	G		5.5	.61	.51		2.82	.88	2.47	W		5.79	.49	.0014	.0319	33.6			
226a	W-12	B	Beasley, gravel bed, log sides	I		24.0	.80	.50		12.10	1.10	13.30	M-6		25.00	.48	.0014	.0320	42.5			
227a	VMC		Bessemer (c), loose stones	F	1,194.0	15.4	3.20	2.38	LR	36.65	1.16	42.35	M		17.78	2.06	.00026	.0321	50.0			
228	S-9	A	Lower, from Big Cottonwood	F	1,000.0	8.0	1.70	1.23	S	9.82	1.03	10.08	M-2+8		9.20	1.07	.000533	.0324	42.8	66	56	C.
229a	SF-55		Smithfield lateral, some cobbles.	H		5.1	.67	.58		2.97	.43	1.29	W		5.70	.52	.000353	.0329	32.0			
230	S-62	A	Yosemite Power Co., Golden Rock.	G	537.0	7.2	1.10	.81	LR	5.82	1.20	6.97	M-VC		7.95	.73	.001629	.0346	34.7	74	69	C.
231	H-15	C	Billings Land & Irrigation Co., lateral 1.	G	400.0	9.5	1.75	1.03	S	9.79	1.12	10.95	M-VC		10.22	.96	.00093	.0349	37.3			
232a	SF-26		Logan and Benson Ward, moss	I		21.0	1.61	1.39		29.14	.84	24.59	M		22.00	1.32	.00033	.0352	40.3			
233	S-18	A	Logan and Hyde Park, gravel	H	550.0	14.5	1.90	1.60	LR	23.14	1.18	27.38	M-VC	i.	17.51	1.32	.0006982	.0364	38.9	73	52	C.
234a	W-9	B	Hillsboro, rough	H		23.0	2.5	2.18		50.10	1.44	72.00	M-6		26.7	1.87	.00060	.0371	42.8			
235	S-53	B	Lateral 2½, Turlock District, sand.	G	1,020.5	23.0	3.10	1.92	S	44.26	.81	35.99	M-VC	i.	24.5	1.80	.000217	.0373	41.1	92	77	A.
236	S-42	A	Cochrane, gravel	G	733.8	14.0	2.10	1.58	S	23.06	1.18	27.15	M-VC	f.	16.62	1.39	.000695	.0379	37.9	77	71	U.
237	S-25	A	Perrault, hard bed, grass	H	610.0	11.5	1.60	1.15	S	13.20	.70	9.28	M-VC	h.	12.48	1.06	.000398	.0381	34.2	59	62	C.
238a	SF-62		Hyrum lateral, rocks, moss	F		6.6	1.20	.84		5.55	.44	2.47	W		7.20	.77	.00029	.0393	29.6			

239	S-46	A	Orr, hard scoured bed	F	1,426.0	15.0	2.80	2.11	LR	31.72	1.44	45.80	M-VC	...	17.81	1.84	.000746	.0397	39.1	70	...	A.
240	S-21	A	Small ditch, hard bed, débris	G	308.0	3.9	.60	.44	S	1.70	.45	.76	W-C	...	4.21	.40	.000919	.0399	23.3	...	...	
241	S-52	A	Capurro, few cobbles	E	300.0	3.2	.90	.86	LR	3.74	.35	.96	W-C	...	4.94	.56	.0003367	.0403	25.6	...	...	C.
242a	SF-24	...	Brigham City Electric Light Co., moss.	F	...	10.7	2.50	1.91	...	20.44	1.52	31.07	...	...	12.60	1.62	.00115	.0424	35.2	...	...	
243	S-4	B	New Rutner, gravel bed	H	600.0	5.5	1.15	.75	S	4.15	.65	2.69	M-6	...	6.15	.68	.00095	.0436	25.6	...	...	C.
244	S-44	A	Sullivan and Kelly, few cobbles.	F	1,010.0	13.0	3.10	2.17	LR	28.18	1.45	40.93	M-VC	...	15.10	1.8	.000894	.0436	35.6	76	70	C.
245	G-2	...	Roller, grass slopes	G	1,000.0	48.0	5.50	4.09	S	196.34	.40	78.35	M-VC	...	50.30	3.90	.000023	.0461	42.1	77	79	
246a	SF-46	...	Brigham City, much vegetation.	G	...	19.6	2.38	1.82	...	35.76	.65	23.40	M	...	20.50	1.74	.00028	.0499	29.6	...	...	
247a	SF-53	...	Thatcher lateral, much vegetation.	G	...	5.0	.70	.51	...	2.57	.42	1.08	W	...	5.30	.48	.00107	.0519	18.4	...	...	
248a	SF-52	...	do	F	...	4.1	.82	.70	...	2.90	.37	1.08	W	...	4.98	.58	.00064	.0529	19.2	...	...	
249	G-5	B	Small ditch, grass lined	G	100.0	5.0	1.00	.64	S	3.21	.32	1.04	M	...	6.01	.52	.00067	.0544	17.3	88	88	
			Cobble bottomed.																			
250a	W-13	B	Beasley	I	...	16.0	.80	.46	...	7.4	1.74	12.90	M-6	...	16.6	.44	.00093	.0220	87.0	...	...	
251	H-31	A	Bitter Root Valley Irrigation Co.	H	600.0	27.0	3.00	2.32	S	62.57	2.27	142.10	M-VC	...	27.57	2.27	.00055	.0262	60.6	...	...	
252	S-10	A	Upper, from Big Cottonwood	H	950.0	11.0	1.70	1.39	S	15.28	1.77	26.90	M-VC	h	15.10	1.17	.001012	.0277	51.2	79	51	C.
253	S-15	A	Logan and Northern, grass	D	630.0	16.2	3.70	2.60	LR	42.72	1.77	75.66	M-VC	...	19.00	2.25	.00037	.0270	61.3	80	51	C.
254	S-51	A	Reno, hand-laid riprap	D	800.0	18.0	6.00	3.92	S	70.59	3.57	251.79	M-VC	...	23.40	3.02	.001129	.0291	61.1	...	...	D.
255	S-43	A	Sullivan and Kelly, laid wall	J	670.0	10.5	3.30	2.45	S	25.70	1.59	40.93	M-VC	d	15.23	1.81	.000603	.0324	48.2	76	70	A.
256a	SF-47	...	Logan and Hyde Park	E	...	1.8	.38	.35	...	.63	1.35	.85	W	...	2.32	.27	.00991	.0337	25.9	...	...	
257a	SF-33	...	Hyrum lateral	I	...	3.6	.27	.22	...	.80	1.02	.81	W	...	4.00	.20	.01212	.0365	20.7	...	...	
258a	SF-57	...	Smithfield lateral	I	...	4.6	.29	.24	...	1.11	1.33	1.48	W	...	4.75	.23	.0171	.0377	21.1	...	...	
259	S-89	A	Beasley, very little grass	I	889.2	14.0	.80	.71	LR	9.97	1.82	18.14	M-VC	i	15.40	.65	.00584	.0383	29.6	58	52	A.
260a	SF-56	...	Smithfield lateral, very uneven	I	...	4.6	.28	.23	...	1.06	1.10	1.17	...	...	4.70	.23	.0170	.0423	17.9	...	...	
			Sidehill cuts with retaining walls.																			
261	H-23	A	Hedge, plastered wall	J	250.0	14.0	3.45	3.08	S	43.10	1.58	68.00	M-VC	...	18.50	2.31	.000132	.0185	90.5	...	...	C.
262	H-27	A	Hedge, earth and gravel bed	J	450.0	13.0	3.15	3.76	S	35.90	1.85	66.50	M-VC	...	17.10	2.10	.00030	.0225	73.8	...	...	
263	H-9	A	Cove, concrete floor	J	900.0	12.0	2.70	1.68	S	20.21	2.30	46.61	M-VC	f	13.81	1.45	.00080	.0228	67.5	...	...	
264	S-17a	B	Logan, Hyde Park and Smithfield.	J	337.0	13.0	2.50	1.73	S	22.49	3.12	70.19	M-VC	...	15.24	1.48	.001852	.0256	59.7	70	55	C.
265	H-26	A	Hedge, concrete wall and floor	J	300.0	12.5	3.15	2.88	S	36.00	1.85	66.50	M-VC	...	16.90	2.13	.00044	.0269	60.5	...	...	
266	S-17b	B	Logan, Hyde Park and Smithfield.	E	100.0	12.5	2.50	1.78	S	22.22	3.16	70.19	M-VC	...	15.50	1.44	.00237	.0278	54.2	70	55	C.
			Miscellaneous sections.																			
267	S-74	A	Lower, Riverside Water Co	E	200.0	10.5	1.50	1.38	S	14.45	1.32	19.04	M-VC	...	12.35	1.17	.00045	.0249	57.4	91	73	C.
268	S-73	A	do	J	750.0	10.0	1.80	1.52	S	15.15	1.26	19.04	M-VC	h	12.22	1.24	.0005253	.0291	49.1	91	73	C.
269	S-17c	B	Logan, Hyde Park and Smithfield.	E	265.0	9.5	2.50	2.15	S	20.40	3.44	70.19	M-VC	g	13.42	1.52	.0030	.0298	50.9	70	55	C.

DESCRIPTION OF CHANNELS.

The descriptions in the following pages are to be considered as supplementary to the table beginning on page 19, which gives all the information necessary to a clear understanding of the hydraulic conditions holding at various tests with the exception of a detailed description of the channel, which would have made the table too cumbersome. The descriptions of the channels follow the same order and are numbered like those in the table, with the exception that data obtained from other sources than the work of this division are abstracted in the Appendix commencing on page 62.

CONCRETE LININGS.

No. 1, Expt. S–26, New York Canal, Payette-Boise project, U. S. Reclamation Service, Idaho. A large canal, in concrete, rough as an orange, with plastered expansion joints. Experiment rated as class C, because water issues from an open check in canal about 600 feet above station 0 and the canal passes into an earth section about 100 feet below station 6. (See Pl. I, fig. 1.) Cross sections developed from office notes of United States Reclamation Service through courtesy of W. G. Steward. Impossible to determine condition of bottom with water in canal. There is a slight curve in the reach which disturbs the filaments of current. For additional data on this canal see Nos. 2 and 3, Table I. Coefficient n=0.0101.

No. 11, Expt. B–4, Ridenbaugh Canal, Nampa-Meridian Irrigation District, Idaho. This test was made two years before and covered about the same reach as in test No. 13 below. Mr. Bark found a slightly lower value for slope than later experimenters, which accounts for the lower value of n found. The preponderence of evidence would indicate that a value of about 0.0125 is right for this nearly perfect piece of concrete, to include both tangents and curves. Coefficient n=0.0110.

No. 12, Expt. S–24. This lining in the same canal as No. 11 is a very smooth, hand-troweled, cement wash on a base of concrete 3½ inches thick. The reach is on tangent with about a 6° curve beginning at station 9. The lining was placed in slabs 16 feet long with iron dowel pins and strips of tarred paper between slabs. After the forms were removed the joints were poured with a neat cement. As a rule the joints are as smooth to the hand as any other part of the lining (Pl. I, fig. 2), though slight cracks are opened during cold parts of the day. This is an exceptionally well-made lining, and this, coupled with the fact that the curves are spiraled into the tangents, accounts for the very low value of n as found by all experimenters. For additional experience on this canal see Nos. 11 to 15, Table I. Coefficient n=0.0121.

No. 13, Expt. S–24a, was made on the same canal as S–24, but the reach included not only the 901 feet of tangent as above, but also the above-mentioned curve, which was about 600 feet long, and a short reach of tangent below the curve, making the total reach 1,819 feet long. As is to be expected, the value of n is a little higher than on tangent. The slabs on curves were but 12 feet long. Coefficient n=0.0129.

No. 14, Expt. F–3. This experiment was made on approximately the same reach of canal as S–24, but was 1,020.6 feet long, with one slight curve in the reach. The slopes of the surface in this and experiments 26 and 28 were found by a line of levels run between the ends of reaches as usual, but the water surface was found by means of a gauge constructed on the piezometric principle. The hydraulic grade as given in the table is the mean of 23 tests. An instrument of this form should give the surface at the time of reading very closely, but the experimenter must be sure that this slope is the same as the one held at the time of the discharge measurement. Coefficient n=0.0124.

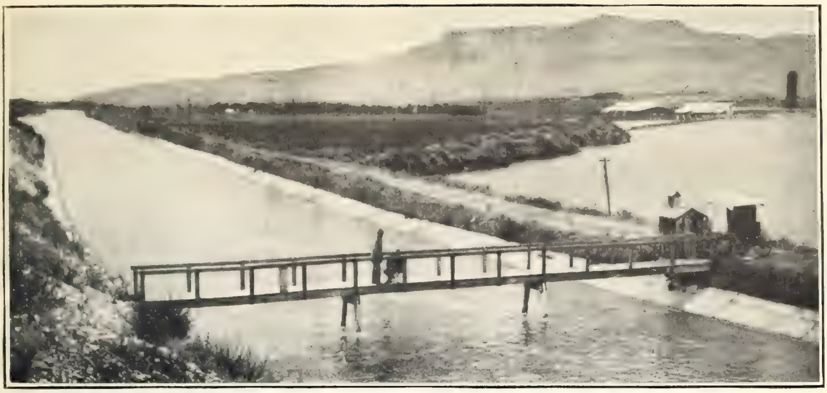

FIG. 1.—NEW YORK CANAL, UNITED STATES RECLAMATION SERVICE, IDAHO.

(No. 1—Downstream. Station 0 is just above meter bridge.)

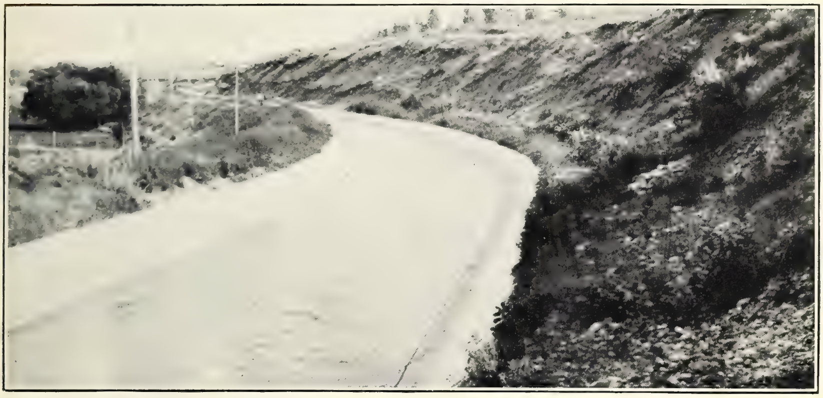

FIG. 2.—RIDENBAUGH CANAL, IDAHO.

(Nos. 12-13—Upstream from Station 15.)

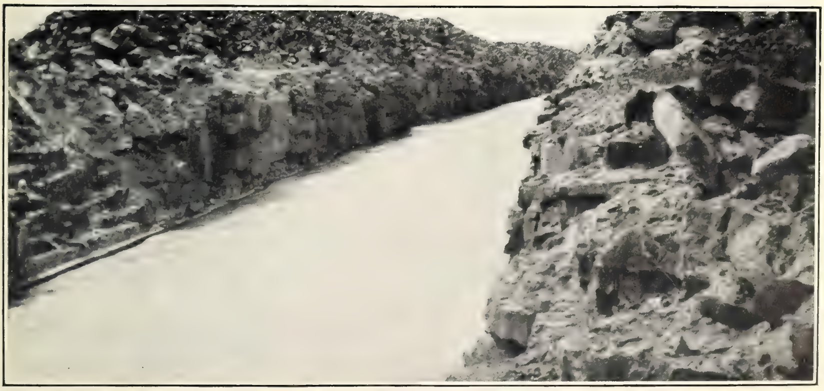

FIG. 3.—NORTH SIDE TWIN FALLS CANAL, IDAHO.

Note top of lining above water line. (No. 25—Downstream from Station 0.)

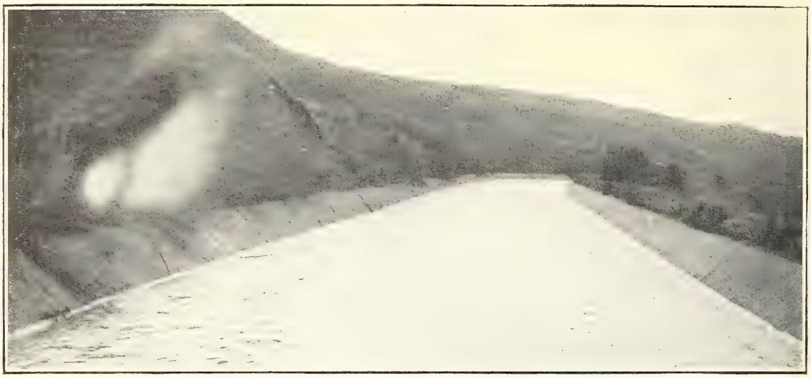

FIG. 1.—DAVIS AND WEBER COUNTIES CANAL, UTAH.

Note projecting expansion joint strips. (No. 29—Downstream from Station 2 plus 49.)

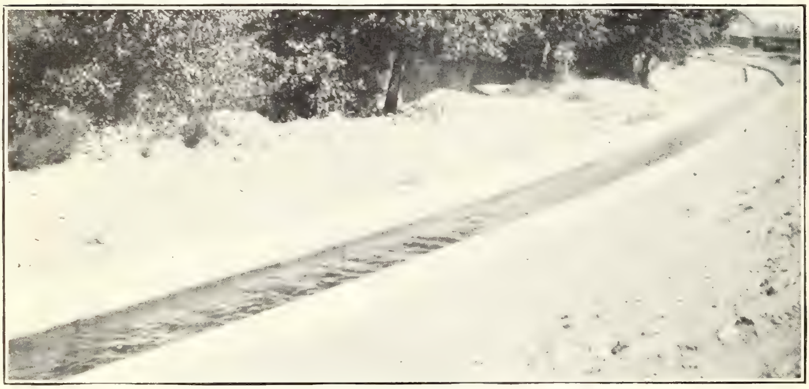

FIG. 2.—HAMILTON MILL FLUME, MONTANA.

(No. 31—Upper part of concrete section.)

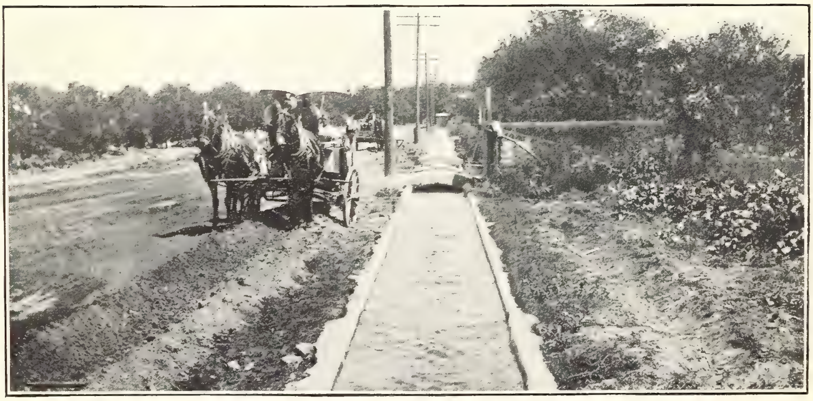

FIG. 3.—SANDERFER DITCH, CALIFORNIA.

(No. 35—Upstream from Station 3.)

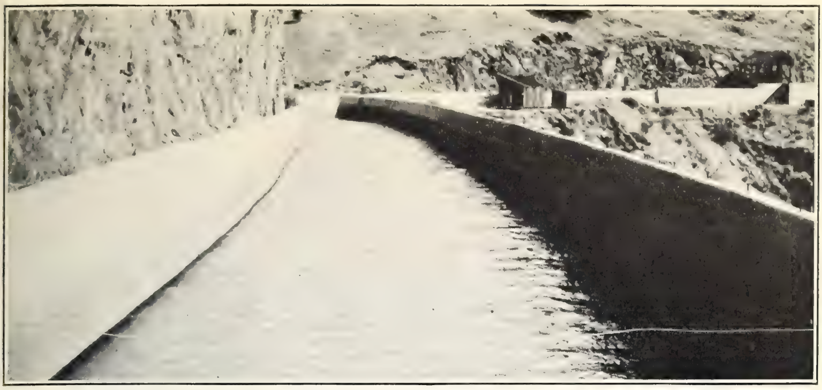

FIG. 1.—MODESTO IRRIGATION DISTRICT MAIN CANAL, CALIFORNIA.

No. 41—Upstream from Station 3 plus 64, on meter bridge.)

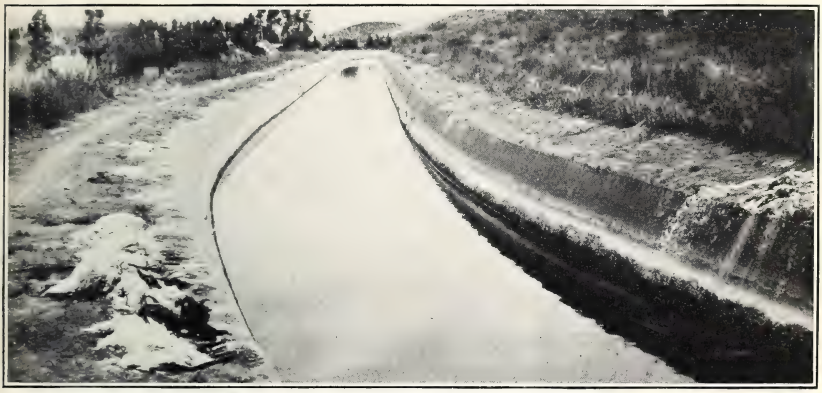

FIG. 2.—SANTA ANA AND ORANGE CANAL, CALIFORNIA.

Note deposit below high-water line. (No. 42—Upstream from Station 12.)

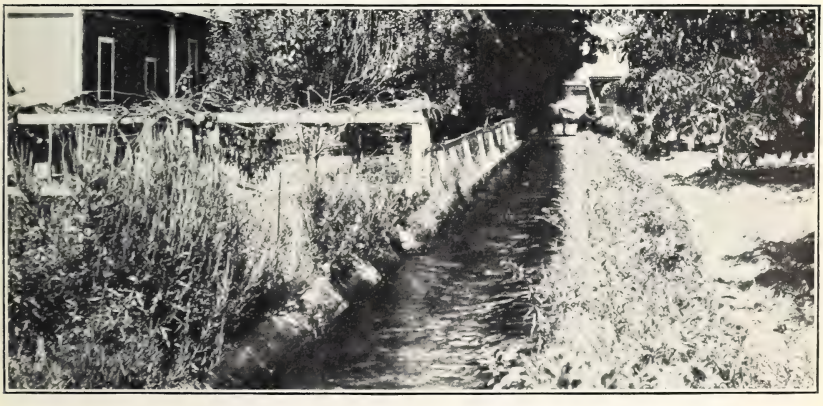

FIG. 3.—LOS NIETOS CANAL, CALIFORNIA.

Note deposit. (No. 43—Upstream from Station 1 plus 50.)

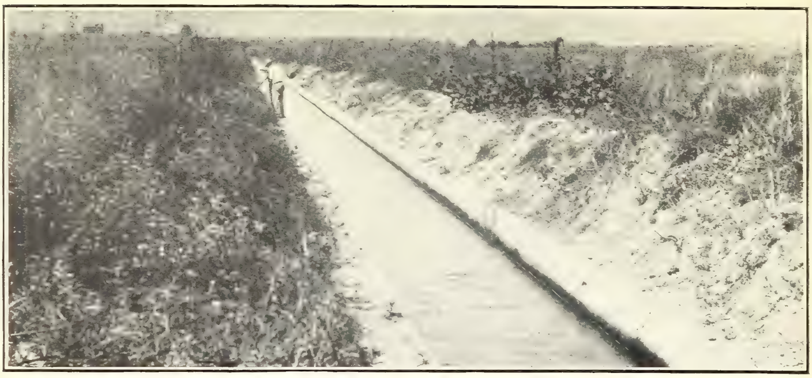

FIG. 1.—ARROYO DITCH, CALIFORNIA.

(No. 44—Upstream from Station 8.)

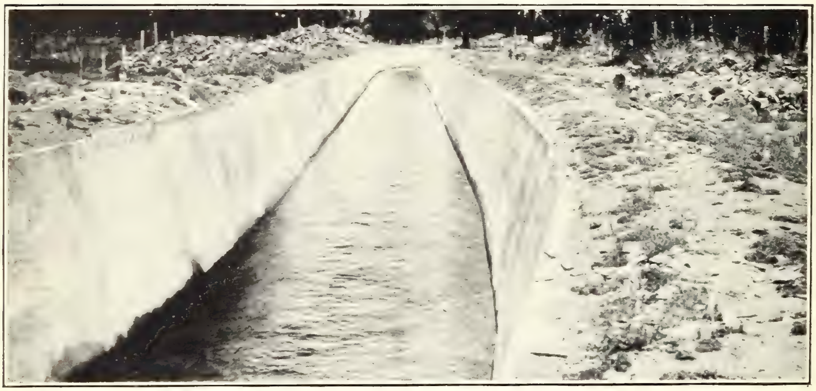

FIG. 2.—NORTH CANAL, BEND, OREG.

(Nos. 46, 48, and 50—Downstream from Station 5. Meter station in distance.)

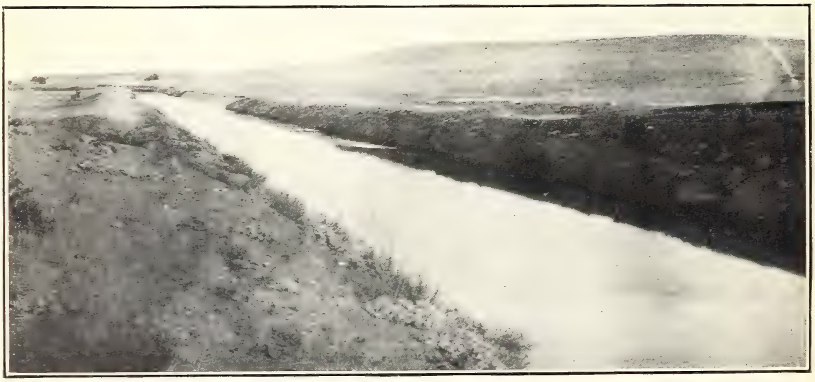

FIG. 3.—MAIN CANAL, SOUTH, ORLAND PROJECT, UNITED STATES RECLAMATION SERVICE, CALIFORNIA.

Concrete section (No. 51) in distance. Earth section (No. 184) in foreground.

No. 25, Expt. S–19, North Side Twin Falls Land & Water Co.'s main canal near Milner, Idaho. As shown in Plate I, figure 3, this concrete lining fills out the main irregularities in a very rough lava-rock cut. An examination of the section below the water line was impossible at the time of making the experiment, and the various cross sections from which the value of R was deduced were taken from office notes. These covered bottom widths and elevations of the bottom at both sides and in the middle. A study of these notes shows that the bottom is undulating and that while the high velocity would prevent the accumulation of sand deposits, and lava rock does not slough off débris to any extent, yet the velocity is retarded by the disturbance in the filaments of current due to the undulations. Coefficient n=0.0138.

No. 26, Expt. F–1, Davis and Weber Counties Canal, Utah. This experiment was conducted in the same canal as tests Nos. 28 and 29, but about 8 miles upstream and about 1 mile below the head gate from the river. Condition of bottom could not be determined, but was probably about the same as in No. 28. The concrete on sides was smooth and unbroken. The hydraulic grade was taken as the mean of five tests with level and piezometer and found to be 0.000413, while constructed grade of this portion of canal was 0.000445. Coefficient n=0.014.

No. 27, McL., Davis and Weber Counties Canal, Utah. See Nos. 26–28–29. Coefficient n=0.0144.

No. 28, Expt. F–2. This experiment was on a reach 468.5 feet long, which was included in the reach 1,000 feet long described in No. 26. The hydraulic grade was taken as the mean of level lines run between 12 settings of the piezometer instrument spoken of under No. 14. The mean of these 12 observations gave a slope of 0.0006168, while the constructed grade of the canal, as stated by the chief engineer, was 0.000626, and in No. 29 the writer found the surface slope to be 0.000629. In the description of conditions B. P. Fleming states that the patches of gravel consisted of all sizes up to 5 inches in greatest dimension and that probably 10 per cent of the area was covered with them, mostly adjoining the toes of the side slopes. This experiment was made about six weeks after No. 26. Coefficient n=0.0146.

No. 29, Expt. S–13, Davis and Weber Counties Canal, Utah. This canal furnishes an example of the retarding effect of wooden expansion joints if they are not so set that they can not project into the canal section (Pl. II, fig. 1). The lining was laid in slabs varying in width from 8 to 16 feet. Strips of wood a little larger than building lath were placed between the slabs with the idea that they would eventually be pulled and the space filled with asphalt. This has not been done, and at present the strips project from 0 to 1½ inches into the section. However, the velocity at the bottom was retarded by small patches of gravel which have probably sloughed off the hillside cut in which the canal runs. This condition will probably be present each season, even though the canal be cleaned out once a year, but the friction factor n can undoubtedly be reduced one or two units in the third decimal place by carrying-out the original idea contemplated in the construction. Coefficient n=0.0154.

No. 30, B–10, King Hill Canal, Idaho. This test was made on a reach covering both tangent and curves. The concrete was not surfaced, but left as hand tamped to grade. After surface coat had set, the 2 by 4 inch end forms were removed and the groove poured with a 1 to 1 mixture of sand and cement. The surface is described as quite rough, especially at the joints. The canal was clean of detritus and moss. Coefficient n=0.0143.

No. 31, H–29, Hamilton flour mill flume, Montana. This flume was constructed recently of a 1 to 7 mixture of cement and sand with some fine gravel. The coat has a few blowholes, but is usually smooth. The concrete was deposited against wood forms and not plastered. The alignment is as follows: 10° curves at stations 4 and 6. Small curves at stations 8+50, 11, 14, and 20+50. The rest of the distance was on tangent (Pl. II, fig. 2). Coefficient n=0.0149.

No. 35, Expt. S–69, Sanderfer Ditch Co.'s main canal, near Whittier, Cal. As shown in Plate II, figure 3, this reach is straight and quite uniform. The bottom is slightly dished. As is the case of all small lined ditches in southern California, the sides and bottom are covered with a rough deposit which entirely vitiates the good results which would be anticipated by using a smooth cement wash such as the one on this ditch. This deposit appears to accumulate on either smooth or rough concrete, so the added expense of the former does not appear to be warranted in view of the results. The water in this ditch was clear and did not carry an appreciable amount of sand. Coefficient n=0.0155.

No. 37, Expt. S–37a, lateral 12, Orland project, United States Reclamation Service, central California. This is a small lined section of general trapezoidal form, but with a slight dishing in the bottom. About 50 feet above station 0 is the lower end of a chute drop, and the ditch below station 2 plus 06. turns to the right 90° in a curve of 34 feet radius. The surface of the channel was a good grade of concrete, but not smooth washed. There was a slight deposit of slimy silt, which would have allowed a low value of n but for gravel scattered throughout the ditch section, which had a great influence on velocity, as the section is small. Coefficient n=0.0160.

No. 38, Expt. S–37. This experiment is on the same lateral as No. 37 but covers a straight reach immediately below the right-angle curve noted above. In the opinion of the writer the value of n in this experiment is better for the gravel condition in a small lined section than that found in the shorter reach used for No. 37. This gravel ranged in size from fine to that of a walnut and had a marked influence in retarding the velocity, as there was more or less movement of the gravel down the channel, which retards velocity more than does stationary gravel. Coefficient n=0.0192.

No. 40, Expt. S–11, South Cottonwood Ward Canal, near Murray, Utah. This is a lined stretch about 450 feet long between an earth section, and a wooden flume. There is a slight curve at the upper end. A deposit of about 0.07 foot of fine sand and rootlike growths covered the bottom and modified the original section of rather rough concrete. A slight deposit of moss and slime also modified the sides of the channel. A reach 350 feet long was chosen in the middle of the lined stretch. Coefficient n=0.0171.

No. 41, Expt. S–55, Modesto Irrigation District main canal, near Lagrange, Cal. As shown in Plate III, figure 1, this reach of canal is on an approximate tangent. There is a very sharp curve about 50 feet below the reach tested. The lining is a very good grade of concrete, being about as rough as an orange. For the small amount of water in the canal when tested the value of n is high, because of the presence of a number of pieces of slate rock that have fallen into the canal from the adjoining cliffs. This influence would probably be materially reduced when the canal is carrying water to capacity. However, this experiment shows the value of cleaning the canal as often as practicable in order to maintain a high carrying capacity which is much desired by this district. Coefficient n=0.0174.

No. 42, Expt. S–63, Santa Ana and Orange Canal, near Orange, Cal. In the reach tested, 1,082.8 feet, there was a gentle curve between stations 5 and 7. As shown in Plate III, figure 2, which was photographed from a position about 200 feet below station 10, this canal has the rough deposit and moss common to southern California ditches. In addition the concrete lining of the bottom has been completely covered by a deposit of soft sand from 0.1 to 0.2 foot deep. The carrying capacity of such ditches could be materially increased by the introduction of numerous sand gates of some form. This lining had originally been a reasonably smooth piece of work, but the deposits had destroyed much of the usefulness of the smooth concrete. Coefficient n=0.0176.

No. 43, Expt. S–70, Los Nietos Water Co.'s main canal, near Whittier, Cal. The surface of the original lining in this canal is fairly smooth, but the deposit common to this region has so changed its character that, aided by the rolling sand, a high value of n is found. This sand was about 0.03 foot deep. The clear water emerges quietly from the lower end of a siphon under a road about 100 feet above station 0. The canal turns at right angles, without curvature, about 100 feet below station 6. However, the depth at the various cross sections remains quite constant, showing that the water was not appreciably checked up by this turn. As shown in Plate III, figure 3, there was a very slight retarding effect due to grass and weeds dragging on the surface of the water near the edges of the channel. Coefficient $n=0.0188$.

No. 44, Expt. S–67, Arroyo Ditch & Water Co.'s main canal, near Whittier, Cal. As shown in Plate IV, figure 1, this rough-finish concrete section has accumulated a deposit of rough mossy growth that greatly retards the velocity of the water. In a few places throughout the reach tested the lining was irregular and not in true alignment, which also tended to increase the value of n. The reach was on tangent, with a sharp angle about 50 feet above station 0 and a gentle curve about 100 feet below station 10. See discussion under Nos. 35, 40, and 42, above. Coefficient $n=0.0188$.

Nos. 45 to 50, Expts. S–31, S–30, S–32, Central Oregon Irrigation Co.'s North Canal near Bend, Oreg. These experiments were conducted with varying discharges, on consecutive days, in identical reaches; (*a*) is on a tangent 240 feet long between a 15° curve above and a 14° curve below; (*b*) embraces 157 feet of tangent, then 154 feet of 14° curve to the right, then 90 feet tangent, then 109 feet of 15° curve to the left, then the tangent that includes (*a*) 240 feet long, then 178 feet of 14° curve which passes into a very rough lava-rock cut about 200 feet below station 10 plus 26.

This lining is a clean-scoured, very rough, and deeply pitted concrete made in a rough lava-rock cut. As shown on Plate IV, figure 2, the cross sectional form is even and the filaments of current are not disturbed except by the curves, but the inherent roughness of the lining accounts for the high values of n. The grade of the bottom of this canal was constructed 0.001 feet per foot.

This lining was a 1 : 4 : 5 mixture, deposited behind shiplap forms against a hand-laid rock wall, filling the cavities in a rough rock cut. Expansion joints of $\frac{1}{4}$ by 4-inch lumber were placed on sides and bottom every 12 feet and left in the concrete.

No. 51, Expt. S–38, main canal, South Orland project, United States Reclamation Service, California. As shown in Plate IV, figure 3, this lined section comes between two earth sections of the canal. The concrete is quite rough and pitted, with slight growths of moss, but not nearly sufficient to account for the high value of n found. The writer can only account for this value because of retarding influences due to the earth channel below the lined reach. Coefficient $n=0.0211$.

No. 53, Expt. S–68, small ditch from pumping plant, California. Although constructed with a smooth-finished cement wash, this ditch shows a high value of n because a dark, crinkly deposit has changed the condition of the walls. Vegetation on the banks dragged in the water and retarded velocity to a slight extent (Pl. V, fig. 1.) This test is not given full weight because the ditch is too small to give a first-class current-meter measurement. The mean of three measurements was used. Coefficient $n=0.0220$.

No. 54, Expt. S–75, Riverside Water Co.'s Lower Canal, Riverside, Cal. This experiment gives a good example of a cement-wash lining in which under favorable conditions in southern California a friction factor of about 0.018 might be expected without eradicating the sand which appears to be ever present in the canals in this vicinity. If the sand were removed by the addition of numerous sand sumps and gates this factor would be reduced to 0.016 or thereabouts. At the time of making the tests on this canal, as shown in Plate V, figure 2, the lining had been broken in scattered spots, allowing vegetation to root and grow. In the bottom of the channel were scattered deposits of loose sand, covering possibly 10 per cent of the bottom area. In some of these deposits moss and water grasses flourished. A gentle curve about 100 feet above station 0 had little or no influence on the flow in the low velocities encountered. This lining was a cement and sand coat about 1 inch thick, applied directly to the trimmed surface of the earth channel. Occasional fractures in such a lining are to be expected. Coefficient $n=0.0221$.

No. 55, Expt. S–71, Riverside Water Co.'s Upper Canal, in Riverside, Cal. While originally a canal lined with a well-built and but lightly pitted cement-wash surface the bottom of the channel has completely lost its identity as a concrete lining in so far as friction is concerned, since there is now more than 18 inches of sand in the bottom. This drifts down the canal in little pockets that look like hoof prints of stock. The positions of these shift rapidly, causing the depth of water at a given point to change 0.4 or 0.5 foot in about 30 minutes. This condition renders a measurement by current meter using multiple points obviously inaccurate, and the writer used the integration method, as the latter will give results as close to those found by multiple points as can be desired. A measurement by this method takes but a few minutes, and the canal bottom in this period probably does not shift sufficiently to vitiate the results. As shown in Plate V, figure 3, there are no curves or structures above the reach tested to change results, and the same condition holds downstream. Coefficient $n=0.0231$.

WOODEN FLUMES.

No. 57, Expt. S–50, Reno Ditch, Reno Light & Power Co., Nevada. This flume is built of 2 by 12-inch surface pine with all cracks battened with 1 by 4-inch strips. This gives a retarding vertical batten about every 12 feet. As shown in Plate VI, figure 1, the flume leads from the cobble-lined ditch, No. 254, to the penstock above the power house. The reach chosen begins about 100 feet below the upper end of flume and extends for 800 feet down a tangent and around part of a gentle curve to a point about 800 feet above the penstock. Coefficient $n=0.0103$.

No. 58, Expt. H–30, Bitter Root Valley Irrigation Co.'s Canal, Montana. This straight flume is built of 2½-inch tongued and grooved finished siding, with butt joints calked with oakum. The interior was therefore free from battens or other retarding construction. Station 0 was about 100 feet below the flume intake from an earth canal. Station 5 is about 50 feet above a trash rack which was clean at the time of measurement and does not appear to effect the flow. Coefficient $n=0.0112$.

No. 59, Expt. B–11, King Hill flume, Idaho. This test was conducted August 7, 1911, in a flume lined with a very smooth roofing material, which was placed in the spring of that year. Longitudinal wooden strips worn very smooth by the water, held the roofing in place. Coefficient $n=0.0115$.

No. 64, Expt. S–34, Big flume, Central Oregon Irrigation Co. near Bend, Oreg. As shown in Plate VI, figure 2, this flume is very sinuous, the reach of 1,100 feet tested having an alignment as follows: Station 0–60 being at the P. T. of a 12° curve right; thence on tangent 329.9 feet; thence around a 20° curve right, 135 feet; thence reversing into a 20½° curve left for 256.1 feet; thence reversing again (at a point near the ladder, in the figure) into a 17½° curve 211.7 feet; thence on a tangent for the balance of the reach, 107.3 feet. The flume was originally constructed of surfaced and sized 2 by 12-inch pine, with cracks battened with ½ by 3-inch strips surfaced on one side and both edges. A washout necessitated rebuilding the flume in part, and a few of the planks and battens in the rebuilt portion were not surfaced. It is a difficult matter to tell one from the other after a few months' use, as a slight deposit of green slime makes the boards very smooth indeed. Bifurcation works divide the water about 200 feet below station 11. The constructed grade was 10.56 feet per mile, or 0.002 feet per foot. Coefficient $n=0.0117$.

Nos. 65, 66, 67, 68, H–16, Alkali Creek flume, Billings Land & Irrigation Co., Montana. Four tests were made in a straight reach of this flume, which is of unsurfaced lumber, somewhat waterworn and with slight deposits of slime and moss. The grade of the bottom is excessive and irregular, causing extensive wave action when oper-

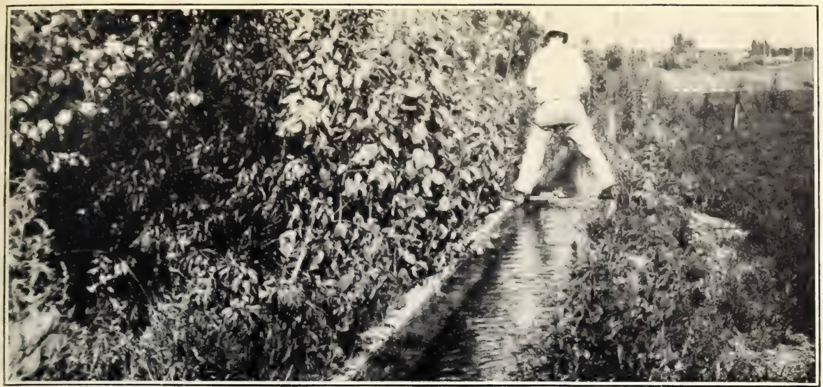

FIG. 1.—SMALL DITCH NEAR WHITTIER, CAL.

Clear water filling concrete section. (No. 53—View upstream from Station 2.)

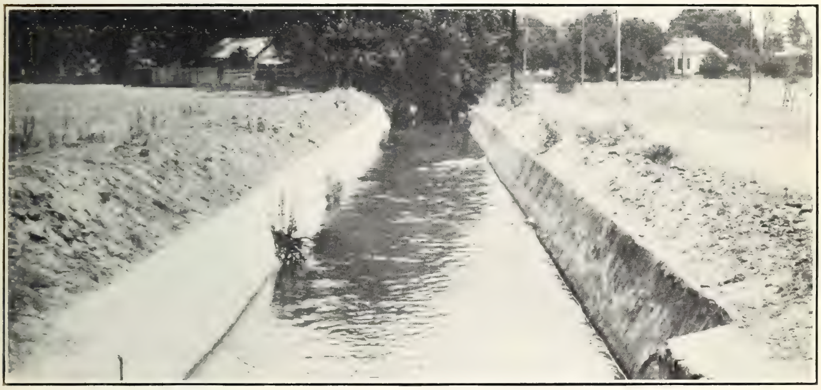

FIG. 2.—LOWER CANAL, RIVERSIDE, CAL.

Note weeds in broken places. (No. 54—Upstream from Station 2.)

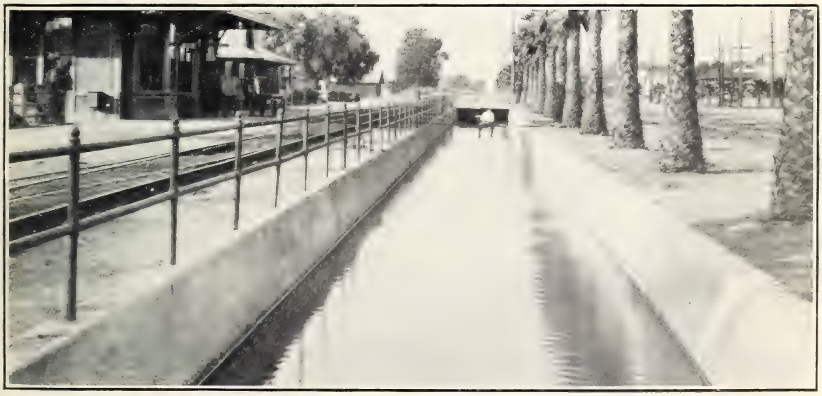

FIG. 3.—UPPER CANAL, RIVERSIDE, CAL.

Note meter station. (No. 55—Upstream from Station 3 plus 30.)

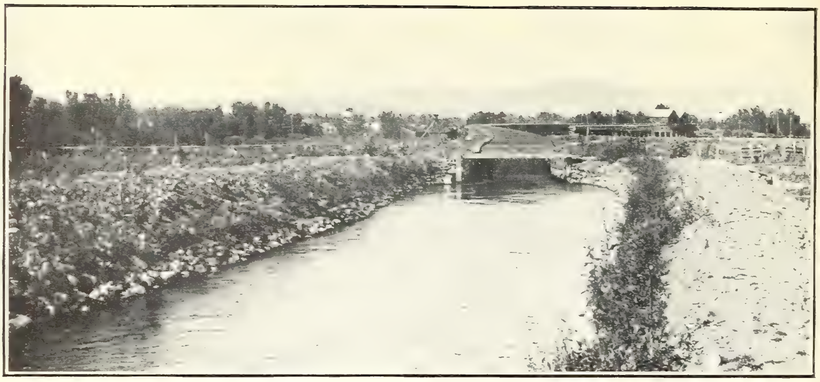

FIG. 1.—RENO DITCH, NEVADA.
(No. 57—Looking downstream into flume. Penstock in distance.)

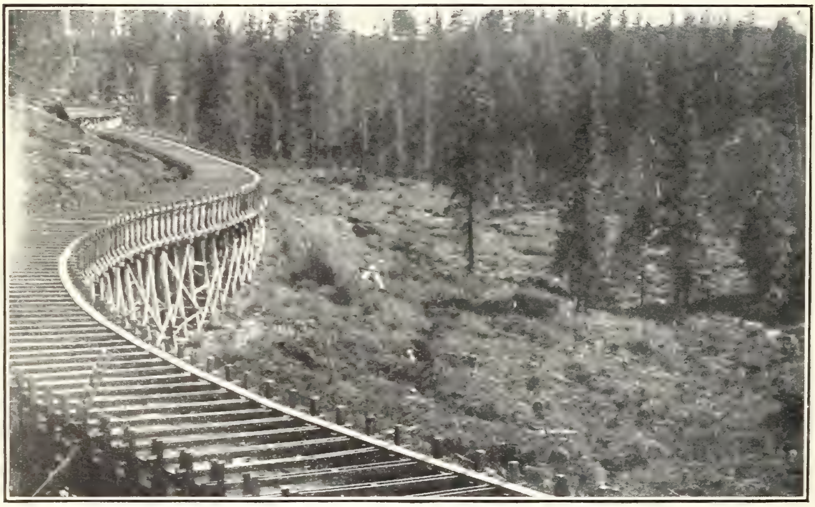

FIG. 2.—BIG FLUME NEAR BEND, OREG.
(No. 64—Upstream from Station 8.)

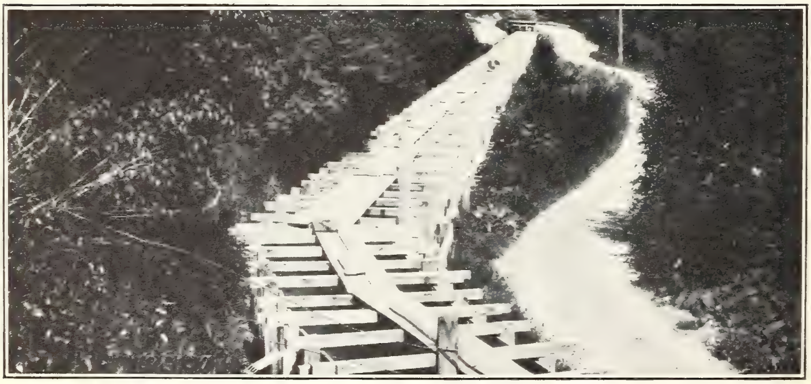

FIG. 3.—TELLURIDE FLUME, UTAH.
(No. 75.) The reach tested was tangent shown. Note sharp angle at bend.)

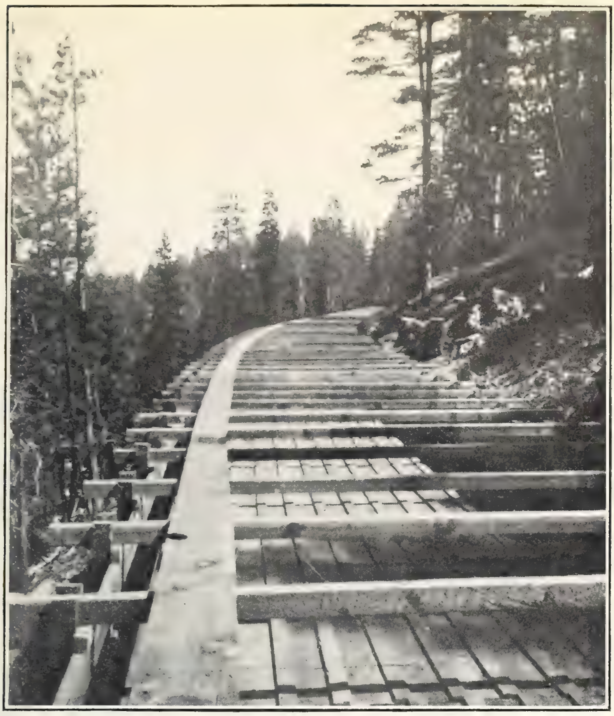

FIG. 1.—ARNOLD FLUME, OREGON.

(Nos. 77 to 80, inclusive—Taken when new. Note battens.)

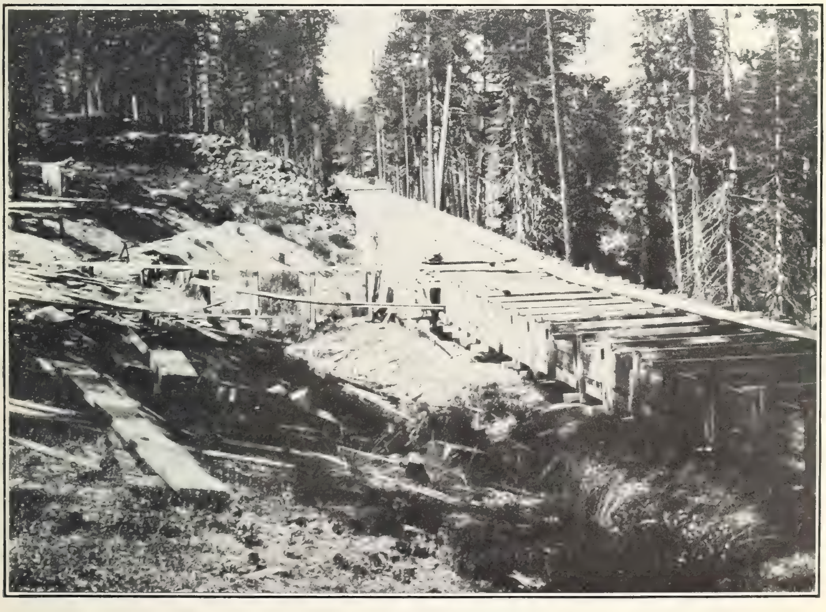

FIG. 2.—ARNOLD FLUME NEAR BEND, OREG.

(Nos. 77 to 80, inclusive—Upstream past Meter Station 15 plus 84.)

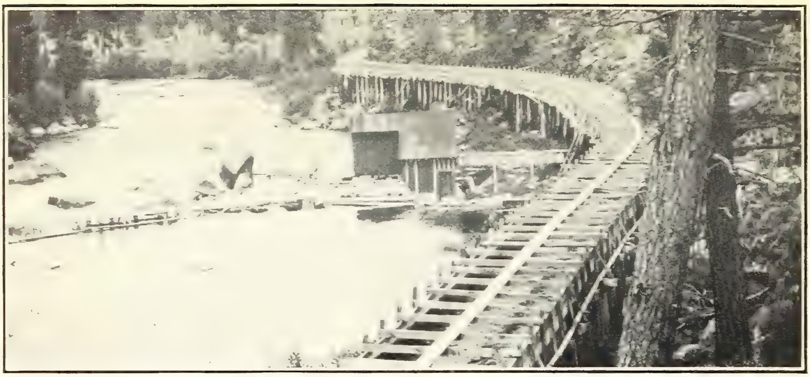

FIG. 1.—SWALLEY DITCH FLUME, OREGON.

(Nos. 84 to 87, inclusive—Downstream from Station 0. Total reach extends to distant tangent.)

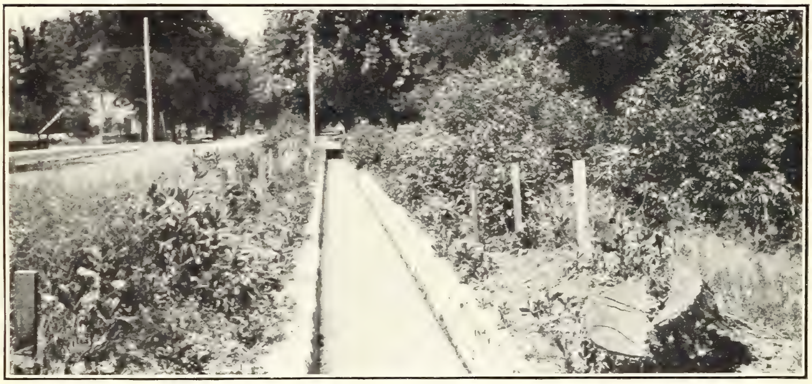

FIG. 2.—JACOBS DITCH, BOISE, IDAHO.

Note trash rack at culvert. (No. 113—Downstream from Station 0.)

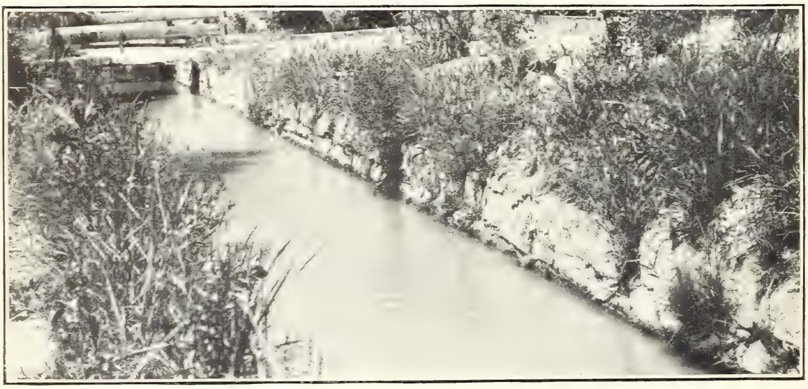

FIG. 3.—JACOBS DITCH, IDAHO

Note unplastered walls. (No. 115—Upstream from Station 1.)

ated to capacity. The flume has been in use nine years, and the inside relined with 1-inch lumber meanwhile. Mr. Harding suggested in designing a flume where such waves are to be expected, that a liberal freeboard be allowed for or else that the crests of the waves be considered the water surface. He has solved n for both assumptions and finds n runs about 0.004 higher where crests are considered the water surface. This difference was quite close throughout the four tests.

No. 70, Expt. H–39, Bitter Root Valley Irrigation Co.'s flume No. 2, Montana. This flume is built of 2½-inch finished tongued and grooved siding. The side boards are 12 inches wide, with the cracks battened with ½ by 2-inch strips. On each side of the cracks in the bottom is laid a ½ by 1-inch strip, leaving a groove about one-half inch wide over the crack. This groove is then poured with an asphaltic filler. The reach chosen follows a contour with the following alignment: Station 0 about 100 feet below upper end of flume; thence 100 feet of about 10° curve right; thence 200 feet tangent; thence 100 feet of about 5° curve right; thence 100 feet tangent; thence 50 feet of about 10° curve left; thence 100 feet tangent to a small bend; thence 50 feet tangent, to end of reach which is about 150 feet above outlet to flume. This reach is very similar to that of No. 71. Coefficient n=0.0125.

No. 71, Expt. H–37, Bitter Root Valley Irrigation Co.'s flume No. 1, Montana. The reach tested is at the lower end of a flume about 1 mile long. The sides were formed of 2½ by 12-inch finished, tongued and grooved lumber with cracks battened with ½ by 1½-inch strips. There are no battens on the bottom. There was a thin coating of sand and gravel in places. The alignment is about as follows: Station 0 to 1 is about 20° curve right; thence 200 feet tangent; thence 300 feet of about 10° curve left; thence 200 feet tangent; thence 50 feet of about 20° curve left; thence 150 feet tangent. The value of n should be compared with those found in Nos. 58, 70, 73. It is higher than for No. 58, because the latter is on a clean tangent. It is lower than for No. 73, which is on a very crooked reach. Coefficient n=0.0127.

No. 72, Expt. H–28, Hedge Canal, Bitter Root Stock Farm, Montana. This test is on a new reach of flume built of 3 by 12-inch finished tongued and grooved lumber. The canal is rough both above and below the flume, which is too short for the best grade of results. Coefficient n=0.0129.

No. 73, Expt. H–32, flume No. 7 of the Bitter Root Valley Irrigation Co.'s main canal, Montana. This is a very crooked flume of the same construction as in No. 58. There was no moss or gravel. The flume follows mountain contours, having sharp curves right and left, with short tangents between. The higher value of n found in this test is to be expected and gives comparative results between straight and very crooked flumes, when compared with the three other tests on flumes of this canal. Coefficient n=0.0135.

No. 74, Expt. H–11, lateral No. 4, Billings Land and Irrigation Co., Montana. This is a small flume 2 feet wide and 2 feet deep. There are no battens and the butt joints are calked with oakum. The inside of the flume is weathered, but appears to have been originally of surfaced material. The flume is generally straight, there being wavy places which slightly distort the true alignment. The ends of the reach are far enough from entrance and exit to the flume to be uninfluenced. Coefficient n=0.0138.

No. 75, Expt. S–16, Telluride flume, Utah Power & Light Co., near Logan, Utah. This test is on a straight reach of flume with an angle of about 20° left, located 35 feet below the end of the reach. See Plate VI, figure 3. The sides are of 1-inch Oregon pine with all cracks battened with ⅜ by 3-inch strips, the vertical battens, about 16 feet apart, being beveled on the upstream edge to reduce friction. The bottom battens appear to be about 6 inches wide, but examination was difficult. All surfaces of wood in contact with water appear to have been surfaced, but are so weathered and waterworn that this point is indeterminate. Coefficient n=0.0141.

Nos. 77, 78, 79, 80, Expts. S–35, a, b, c, Arnold flume, Central Oregon Irrigation Co., near Bend, Oreg. Tests were made on various sections of this flume, covering curves and tangent and both. The flume shown in Plate VII, figures 1 and 2, is about 3 years old and was constructed of green pine lumber, with cracks battened with 1 by 4-inch strips in the first 400 feet of the total reach and with 1 by 6-inch strips in the lower part.

Test S–35 covers the whole reach 2,200 feet long, embracing 437 feet of 15° curve, then 1,147 feet of tangent shown in figure 2; then 616 feet of 20° curve with a short tangent at the lower end. Test lettered "a" covers the same 15° curve, "b" covers the long tangent, and test "c" covers the 20° curve and the short tangent. The value of *n* should have been lowest on the long tangent when judged by the appearance of the channel.

No. 82, Expt. H–22, Hedge Canal, Bitter Root Stock Farm, Montana. The portion of this flume tested is about 14 years old. The lining is 3-inch tongued and grooved lumber, surfaced on the water side. There is no moss and only an occasional piece of gravel. The flume follows a mountain contour with heavy curvature, brought about with chords 16 feet in length. This accounts for the rather high value of *n*. Coefficient $n=0.0153$.

No. 83, Expt. H–24, Hedge Canal, Bitter Root Stock Farm, Montana. This flume is of the same age and general description as that tested in No. 82. It is clean of gravel except on the inside of curves. Coefficient $n=0.0155$.

Nos. 84, 85, 86, 87, Expt. S–33, Swalley Ditch near Bend, Oreg. This flume (shown in Pl. VIII, fig. 1) is of rough pine lumber with ½ by 4-inch battens on all cracks. It is weathered, but not made as smooth as if originally surfaced. There is a small amount of slime present. Reach (a) is on the first tangent in the view. Coefficient $n=0.0157$. Reach (b) covers the last 35 feet of the tangent in the view then around the curve to the left. Coefficient $n=0.0149$. Reach (c) covers the second tangent and the sharp curve, of about 75 feet radius, to the right. Coefficient $n=0.0157$. Reach (d) covers all of the above reaches. Coefficient $n=0.156$.

No. 88, Expt. S–61, Golden Rock Lower Ditch, Yosemite Power Co., California. This test was made on a reach of flume made of unplaned pine lumber 1½ by 15 inches. There were three battens in the bottom, each ½ by 4 inches. There were no battens on the side within the water section. The water was clear. There was no perceptible growth or slime on the wood. No structures were within a reasonable distance of the reach chosen, although a gentle curve ended about 30 feet above station 0. Coefficient $n=0.0159$.

No. 89, Expt. S–58, Modesto Irrigation District main canal, California. This wooden flume, built of 2 by 12-inch lumber, is battened with 1 by 4-inch ship-lap with the groove on top. The latter is then poured with asphalt. There are no battens on the bottom, which was covered with about one-half inch of sand. The dripping asphalt had rendered the sides quite rough, and the value of *n* found is about what might be expected. The flume is straight, with water in the lower end falling over check boards. For this reason and since the water raised in the canal about 0.2 foot during the measurement, the writer has classed this test B. There was no growth or slime noticeable. Coefficient $n=0.0163$.

No. 90, Expt. S–6, lateral of Jordan and Salt Lake City Canal near Salt Lake City. This covers a straight stretch of old flume of rough lumber. There are no battens in the bottom, but the first batten up on the sides was sometimes in and sometimes out of the water through the reach tested. There was no slime, gravel, or moss present, but the flume was wavy, and the bottom on a wavy gradient. There was a sharp turn without curvature about 150 feet below station 4. Coefficient $n=0.0167$.

No. 91, Expt. S–48, Wheeler Ditch near Reno, Nev. This flume is made of 2 by 14 inch rough pine lumber with 1 by 6 inch battens. There are occasional deposits of gravel, and the sides are slightly waterworn and have a slick deposit of silt. A sharp curve occurs about 50 feet above station 0, but the reach tested is practically straight. Coefficient n=0.0167.

No. 93, Expt. G–3, Roller flume, Louisiana. This flume was about 14 years old, with the exception of a portion of the reach tested, about 75 feet long, which had been repaired with new cypress lumber. The original lumber was unsurfaced, but at present is covered with a slimy growth. The lumber was parallel to the axis of the canal, but the surface was slightly irregular. Coefficient n=0.0191.

No. 94, Expt. S–76, Riverside Water Co.'s Lower Canal near Riverside, Cal. The side boards of this flume were of vertical tongued and grooved lumber, making a very rough interior. The bottom was painted with a tar or asphalt product, and the posts were in such condition that the flume sagged and was out of line in numerous places. The value of n as found for this flume may be taken as that of a flume in exceedingly poor condition but without appreciable deposits of sand or gravel. It is understood the company expects to replace this flume in the near future. The reach tested is straight. Water enters from a cement-lined section about 50 feet above station 0 and leaves the flume into an earth ditch about 50 feet below station 7 plus 46. Coefficient n=0.0196.

No. 96, Expt. S–65, Fullerton Ditch of the Anaheim-Union Water Co., California. This flume has the bottom so covered with soft sand that it classes more nearly with an earth section. The lumber was unsurfaced, and a growth of moss retards velocity for about 0.1 foot from each side. The reach tested was straight, but there is a sharp curve about 50 feet above station 0 where the earth canal joins the flume section. About 15 feet below station 6 plus 72 the water enters the earth section again. Coefficient n=0.0202.

MASONRY-LINED CHANNELS.

No. 113, Expt. S–29, Jacobs Ditch, Boise, Idaho. This test is on a straight stretch of ditch. As shown in Plate VIII, figure 2, the sides are of first-class rubble masonry with all cracks smoothly plastered with cement. The bottom is smooth cement lining laid like a good grade of sidewalk. About 50 feet below the lower end of the reach the ditch passed through a vertical trash grating, where there was a loss of head of about 0.05 foot. This grating was kept clean of débris during the test. Coefficient n=0.0130.

No. 115, Expt. S–27. This test was made on the same ditch as No. 113 above, but this reach is lined on both sides and bottom with dry laid, unchinked rubble, as shown in Plate VIII, figure 3. The bottom is quite irregular, with scattered loose cobbles. A clean grating came a short distance below the reach, as in No. 113. Coefficient n=0.0235.

No. 116, Expt. S–28. This test also is on the same ditch as No. 113 above. This reach, one city square long, came between the reaches in No. 113 and No. 115 above, It appeared to have been originally like No. 113, except that the bottom was not lined. There were several cobbles throughout the bottom of this reach, and this probably accounts for the fact that the value of n is slightly higher than for No. 115, while to all appearances it should have been slightly lower. A grating similar to the ones noted above came below the lower end of the reach. Coefficient n=0.0250.

No. 117, Expt. S–45, Orr Ditch, Reno, Nev. As shown in Plate IX, figure 1, the sides are quite smoothly built rubble, with most of the cracks well plastered, but the bottom is covered with shifting sand and loose cobbles so that, if lined, the lining is completely concealed. The lined section ends shortly below the lower end of this reach, passing into an earth channel. This test exemplifies the need of keeping sand and gravel from a lined section if the low value of n that might be expected is to be realized. Coefficient n=0.0298.

EARTH CHANNELS.

No. 119, Expt. S–2, Farmers' (Tristate) Canal, Nebraska. This test and also No. 120 are on long, straight reaches of a large canal, constructed in Brule clay. An engineer connected with the original construction states that in the original design the value of *n* was estimated as 0.025, but, as shown in Plate IX, figure 2, the canal is running to but partial capacity, and the mean velocity is almost sufficient to scour the material. It had one riffle midway of its length, due to old bridge approaches jutting into the canal. The values of *n* in Nos. 118, 119, and 120 are comparable, as the Interstate Canal is in the neighborhood of the Tristate. A fringe of grass extends along the edge but retards only a very small part of the flow. The bottom is extremely even, smooth, and hard, and with the addition of a coating of sediment from the murky waters of the North Platte River, appears to be very efficient. Gentle curves adjoin both upper and lower ends of the reach. For further notes see No. 120. Coefficient $n=0.0130$.

No. 120, Expt. S–1, Farmers' (Tristate) Canal, Nebraska. This reach (Pl. IX, figs. 2 and 3) was perfectly clean cut throughout its length, and in the opinion of the writer gives the better value of *n* than reach in No. 119. In both tests the fall is slight, and the mean value of the results of several tests with the level was accepted. The reach is a tangent between two gentle curves. The bottom was as described in No. 119. Coefficient $n=0.0164$.

No. 126, Expt. S–83, Maricopa Canal, Salt River project, United States Reclamation Service. This reach was part of a long stretch of canal with a clean, sandy bottom and a slight fringe of grass along the edge, but the influence of the latter was practicably negligible (Pl. X, fig. 1). The slope is very gentle, so that a very slight error in the levels would appreciably affect the value of *n*. The measurement with current meter was made above the section tested, where the velocity was greater. Coefficient $n=0.0166$.

No. 127, Expt. S–3, Winter Creek Ditch, Nebraska. This test was made on a long, straight reach of ditch, with very clean, hard bottom, in a cemented material. A fringe of grass bordered both edges. A stiff wind was blowing directly down stream during the test, and a value of *n* of 0.0180 is probably better for this canal under normal conditions than that actually found by the measurement made. Coefficient $n=0.0170$.

No. 130, Expt. H–7, Billings Land & Irrigation Co.'s Canal, Montana. This test was made on a straight reach of canal excavated in clay loam soil. The little grass at the edges is of slight consequence, as the bottom is slick, though roughed by cutting in places. The mean velocity, 2.45 feet per second, was about the limit, as cutting was taking place where the bottom was not protected with a deposit of gravel. A downstream wind probably reduces the value of *n* from about 0.018, making it quite comparable with No. 127 above. Coefficient $n=0.0174$.

No. 132, Expt. H–5b, Cove Ditch, Montana. This test is on the same ditch, with same channel conditions as No. 133. This reach is all curve, the first 300 feet being on a 30° curve, while the ensuing 300 feet is on a reverse 30° curve. While the slopes and cross sections are quite different, the value of *n* for this test and for No. 133 agree quite closely. Coefficient $n=0.0180$.

No. 133, Expt. H–5a, Cove Ditch, Montana. This reach is part tangent (station 0 to station 2) and part on a 20° curve (stations 2 to 4). The ditch is 6 years old. Originally excavated in sandy loam soil, the bottom is now covered with a silt deposit. A fringe of grass retards the velocity at the edge, but not the main flow. Coefficient $n=0.0186$.

No. 134, Expt. H–19, Billings Land & Irrigation Co's. main canal, Montana. This reach of canal follows a gentle hillside contour, although practically straight. There is a little sand and fine gravel scattered over a general bottom of clean soil. The

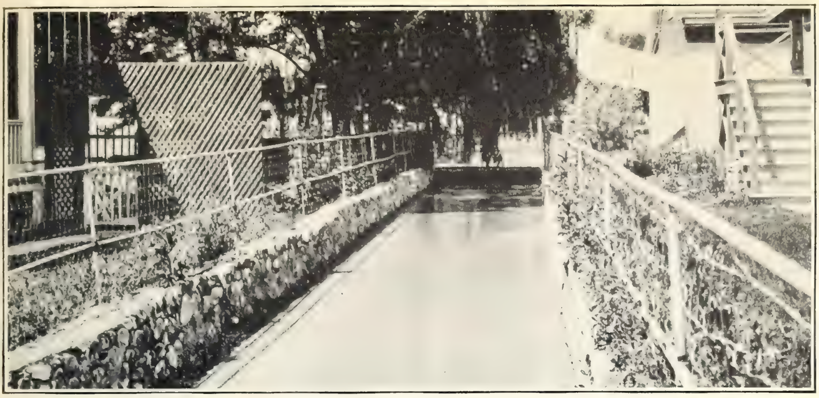

FIG. 1.—ORR DITCH, RENO, NEV.

(No. 117—Upstream from Station 1 plus 30. Station 0 is at bridge shown.)

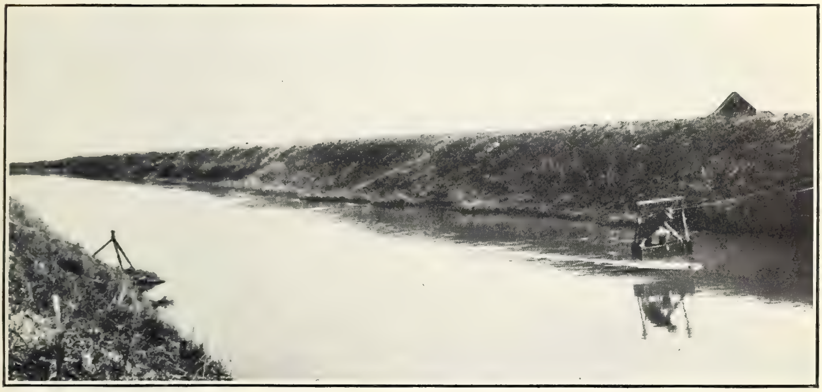

FIG. 2.—FARMERS' (TRISTATE) CANAL, NEBRASKA.

(No. 120—Downstream past Meter Station 6.)

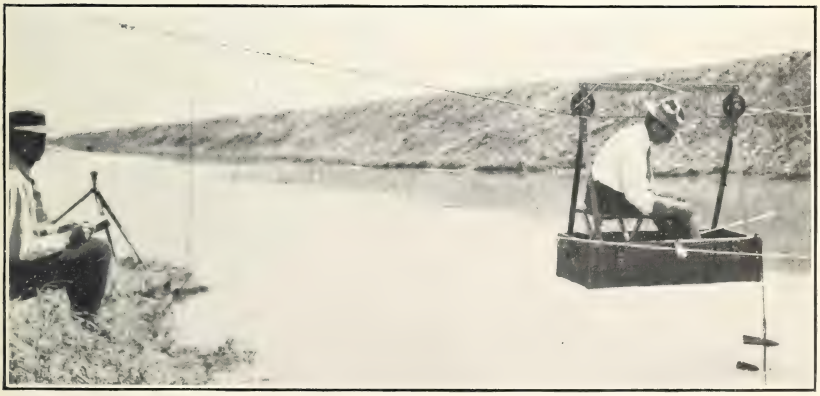

FIG. 3.—FARMERS' (TRISTATE) CANAL, NEBRASKA.

(No. 120—Portable rating car and meter station.)

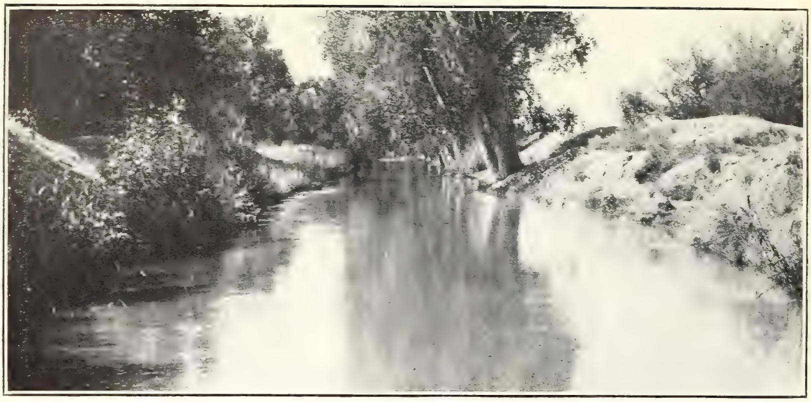

FIG. 1.—MARICOPA CANAL, UNITED STATES RECLAMATION SERVICE, ARIZONA.
(No. 126—Downstream from Station 0.)

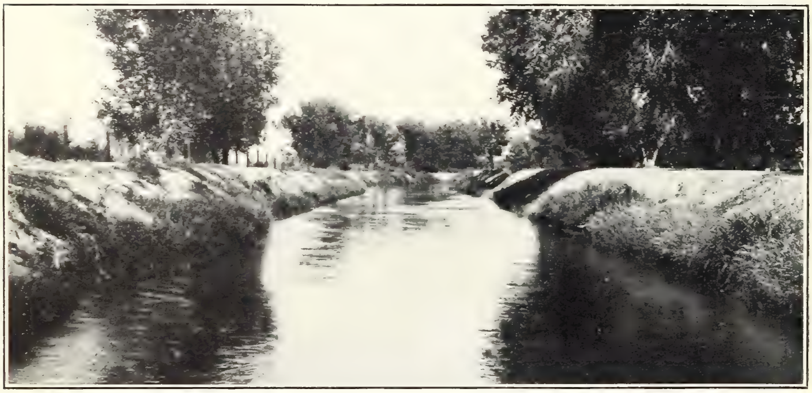

FIG. 2.—GRAND CANAL, UNITED STATES RECLAMATION SERVICE, ARIZONA.
(No. 135—Upstream from Station 10.)

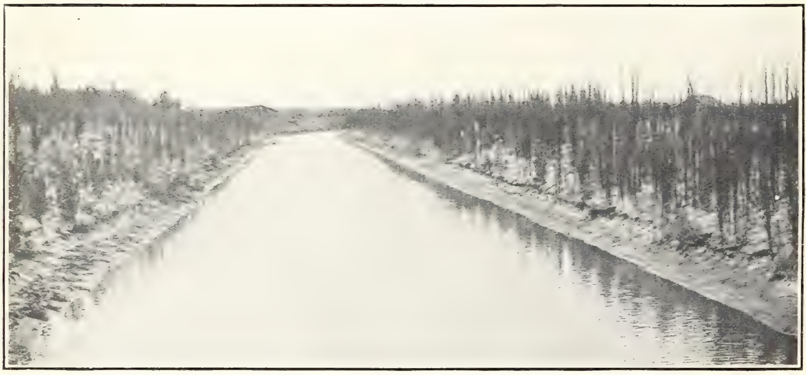

FIG. 3.—LATERAL 7, TURLOCK IRRIGATION DISTRICT, CALIFORNIA.
Note general high-water line. (No. 149—Downstream from Station 0.)

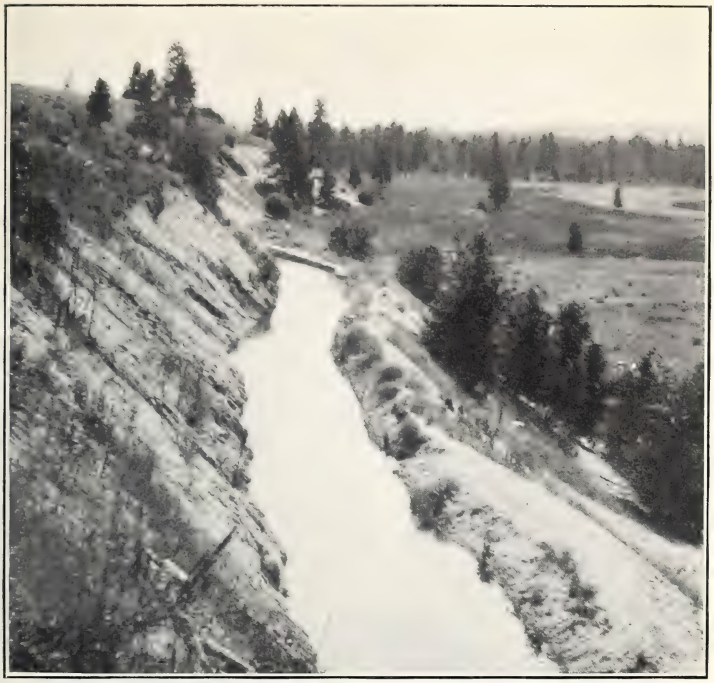

FIG. 1.—HEDGE CANAL, MONTANA. (No. 161.)

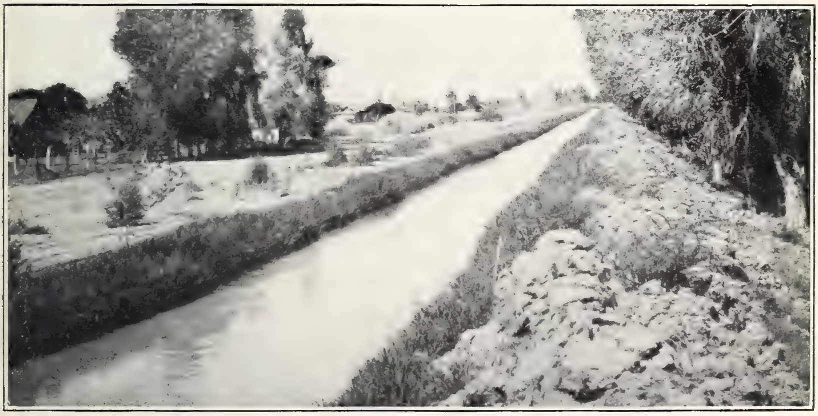

FIG. 2.—BIRCH CANAL, IMPERIAL VALLEY, CALIFORNIA.
(No. 162—Downstream from Meter Station 5.)

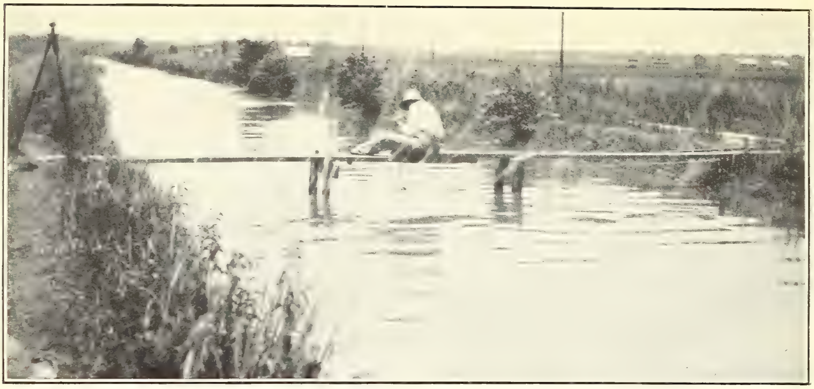

FIG. 1.—CROWLEY CANAL, LOUISIANA.

(No. 164—Upstream from meter station.)

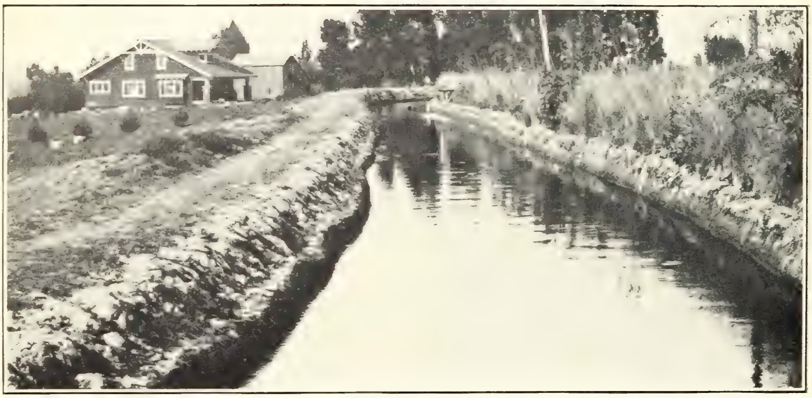

FIG. 2.—SANTA ANA AND ORANGE CANAL, CALIFORNIA, JUST AFTER CLEANING.

(No. 172—Upstream from Station 10.)

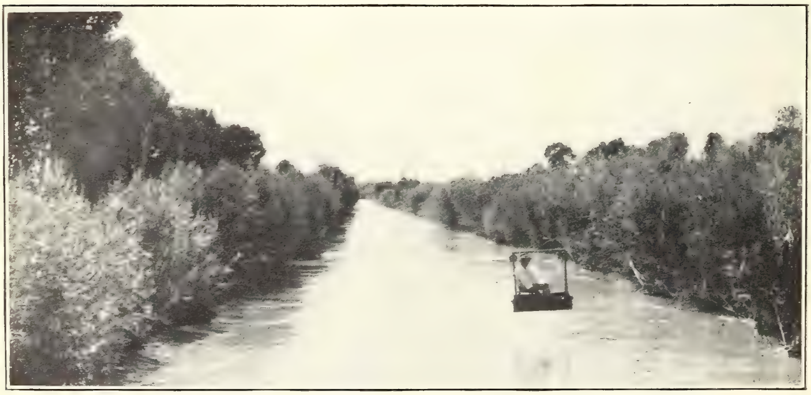

FIG. 3.—CENTRAL MAIN CANAL, IMPERIAL VALLEY, CALIFORNIA.

(No. 173—Downstream. Portable rating car over Station 0.)

velocity in this canal (mean 2.30 feet per second) appears to be about right for this soil, as the middle of the section is clean without cutting and there is a slight deposit of silt and mud along the sides. A downstream wind perhaps gives a value of n slightly below what might be expected. Coefficient $n=0.0181$.

No. 135 Expt. S–82, Grand Canal, Salt River project, United States Reclamation Service. This reach covers a clean-cut stretch, straight except for a gentle curve about 250 feet long, shown in Plate X, figure 2. Originally excavated in a clay loam soil, the section now has a deposit of clean sand in the middle and slick, silty mud near the sides. The fringe of grass shown in the view is slightly above the general highwater mark and had little influence on the reach when tested. Coefficient $n=0.0183$.

Nos. 137, 138, 139, and 140, Expts. H–18, Billings Land & Irrigation Co., Montana. These tests were made on the same reach of ditch, with varying discharges of water. The reach is straight, with a curve nearly adjoining each end. The bottom of the canal, which was originally excavated in Benton shale, is covered with fine sand. The shale at the sides has broken to a fine, slick clay. The cross section is quite regular. Although the discharge varied from 92 to 172 second-feet, the value of n does not vary materially. The tests are lettered in order, a, b, c, and d. After the first two tests a slide came into the canal below the reach tested and had the effect of checking up the water so that the slope was quite different between tests a, b, and c, d. The slide, of course, caused the area of the water section at the lower end to exceed that at the upper end, hence changing the velocity and necessitating a correction for change in velocity head. Cross winds, which were blowing during tests c and d, might easily have effected the slope sufficiently to account for the variation in the value of n. These four tests would not be considered as showing that there is any variation in n with a variation in the value of R, or V.

No. 141 Expt. H–6, Billings Land & Irrigation Co., Montana. This test was made on a straight reach, between gentle curves. The canal, originally excavated in Billings clay, is generally clean, but has a little fine gravel in the bed and some fine silt deposit near the sides. A few cattle tracks and a little grass had a slight retarding effect near the sides, but did not effect the main flow. Coefficient $n=0.0188$.

No. 142, Expt. S–87, Maxwell Ditch, Colorado. This ditch follows a mountain contour. The sides were rather irregular, with a fringe of grass, while the bottom was free from growth and covered with sand and fragments of rock, while the low velocity allowed a silt deposit near the banks. The slope is so gentle that a very small error in levels would materially effect the value of n. For this reason the writer has given but a B rating to this test. Coefficient $n=0.0192$.

No. 145, Expt. H–33, Bitter Root Valley Irrigation Co., Montana. This test was made on a reach of canal following a contour, giving gentle curves joined by short tangents. The bottom is covered with sand and fine gravel with an occasional cobble of two-fist size. The reach is uniform in cross section, which probably accounts for a lower value of n than would be expected in this type of canal. Coefficient $n=0.0196$.

No. 149, Expt. S–57, lateral No. 7, Turlock Irrigation District, California. This canal was tested so late in the season that it was carrying but a small portion of its capacity. The reach is straight, in hard-packed smooth sand. The water being low, the grasses on the banks did not affect the flow at the time of the test (Pl. X, fig. 3). The slope is so gentle that a slight error in levels would appreciably affect the value of n. Coefficient $n=0.0202$.

No. 151, Expt. H–17, Billings Land & Irrigation Co., Montana. This reach of canal, located 400 feet below a tunnel and 200 feet above a flume, is in sidehill excavation of mixed earth and sand-rock with some shale. It was fairly clean, with some loose rock and sand deposits, while there is a slight growth of trailing moss at the lower end. Coefficient $n=0.0204$.

No. 155, Expt. H–34, Bitter Root Valley Irrigation Co., Montana. This test was made on a ditch in its fifth year of operation. The reach is straight, with bottom and sides covered with graded sand and gravel, to cobble size. The sand filling the interstices between larger pieces probably accounts for a value of n far below that of a cobble ditch. Coefficient $n=0.0208$.

No. 157, Expt. H–35, Bitter Root Valley Irrigation Co.'s Canal, Montana. This reach of canal, rather irregular in form, was excavated in hardpan. Drifting sand has smoothed over some of the irregularities. The alignment is as follows: Stations 0 to 3, small reverse curves; 3 to 7, tangent; 7 to 7+50, a 20° curve; 7+50 to 10, tangent. Coefficient $n=0.0211$.

No. 158, Expt. H–14, lateral No. 2, Billings Land & Irrigation Co., Montana. This test was made on a straight reach of ditch, originally excavated in sandy loam soil with some gravel. The present condition of the bottom is smooth, unshifting sand, evenly distributed. The writer is of the opinion that this test is quite comparable with No. 149 above. Coefficient $n=0.0212$.

No. 160, Expt. G–1, Morris Canal, Louisiana. This reach covers a straight section of a large rice-irrigation canal. The previous winter it had been plowed, leaving the bed rough. Water grasses retarded the velocity near the edges. The slope is very gentle, making an accurate determination thereof difficult. The value of n is lower than the writer would expect from the description. Coefficient $n=0.0216$.

No. 161, Expt. H–25, Hedge Canal, Montana. This test was made on a reach of canal excavated in soft granite sidehill. The present section is covered with disintegrated granite, mostly less than ½-inch size, but there are a few up to two-fist size. The general condition of alignment is brought out in Plate XI, figure 1. Coefficient $n=0.0216$.

No. 162, S–78, Birch Canal, Imperial Water Co. No. 1, California. This canal was originally excavated in alluvial silt soil, but deposits of sand on the bottom and growths of grass looking like half-grown oats have completely changed the nature of the channel. The water in this valley, from the Colorado River, is heavily charged with silt at all times of the year, and this forms a slick deposit which will withstand a high velocity before scouring. Prior to 1910 but little sand came down the canals, and the value of n was about 0.017 for canals free from growths, but during the past few years the energy required to transport more or less shifting sand has increased the value of n. The conditions and values in this test and No. 215 are directly comparable, the higher value of n in No. 215 being due to the denser growth of grass as shown in the views, Plate XI, figure 2. Coefficient $n=0.0217$.

No. 164, Expt. G–6, Crowley Canal, Louisiana. This test was made on a straight reach of rice canal. Before the beginning of the irrigation season the canal bed had been plowed and harrowed. Grass interfered with velocity near the sides. (See Pl. XII, fig. 1.) Coefficient $n=0.0219$.

No. 167, Expt. H–8, high line of Big Ditch, Montana. This test gives a good example of what may be expected in a ditch of this type. Originally constructed in a gravel soil, the low velocity has permitted the deposit of silt until the bed of the ditch is smoothed over and the value of n is much smaller than it was in the new ditch. This reach follows contours with sharp curves, joined by short tangents. Coefficient $n=0.0220$.

No. 172, Expt. S–64, Santa Ana and Orange main canal, California. This test shows the value of cleaning a ditch to increase the carrying capacity. The alignment (Pl. XII, fig. 2) follows a gently curving contour. The reach had been well shoveled out within a few days, removing all retarding influence from grasses and moss. There was a very little soft sand near the sides of the section with occasional pockets of sand. The value of n is comparable with that in No. 204, which is on the same kind of a canal subject to the same conditions but has not been cleaned recently. Coefficient $n=0.0221$.

No. 173, Expt. S–80, central main canal, California Development Co., California. This test was made on a long reach of straight canal. The banks were nearly vertical as left by cleaning of silt with a bucket dredge. The bottom is very hard and quite regular, despite this method of cleaning. The velocity was retarded for about 1 foot from each bank by a growth of tules. The silt-laden waters form slick banks. Plate XII, figure 3, shows the reach tested and the portable rating car in action. If freed from growth at all times, which is impracticable in this region, the value of n would be under 0.020. For small canals in this region see Nos. 162 and 215. Coefficient $n=0.0221$.

No. 174, Expt. H–20, Billings Land & Irrigation Co., Montana. This canal was originally constructed in varied strata having an earth surface underlaid with a stratum of gravel, while the bed of the canal was in Benton shale. This has now been covered in places with graded gravel. In general the upper end of the reach tested had a smaller sectional area, consequently a higher velocity, and the gravel was scoured clean, while the lower end of the reach had a lower velocity, and the gravel influence had been reduced by the deposit of silt. Coefficient $n=0.0221$.

No. 175, Expt. S–84, Salt River Valley Canal, Salt River project, United States Reclamation Service, Arizona. This test was made on a straight reach of canal originally constructed in graded gravel underlying silty loam soil. The high velocity encountered (mean 3.12 feet per second) scoured the bed of the canal, exposing hard-packed small gravel, while near the sides a slick deposit of silt formed a surface with but little retarding action on the water. The fringe of grass and small roots at the extreme edges (Pl. XIII, fig. 1), influenced but a very small portion of the flow. Coefficient $n=0.0222$.

No. 178, Expt. H–2, Big Ditch near Billings, Mont. This test was made on a canal originally excavated in Billings loam, which tends to be clayey. The bed of the canal is in the original earth with a slight deposit of sand which undercuts beneath the feet in wading, showing that the mean velocity, 2.09 feet per second, was almost sufficient to cause scouring of sand deposit. Fine mud has been deposited at the sides where the velocities are low. Coefficient $n=0.0225$.

No. 179, Expt. H–38, Bitter Root Valley Irrigation Co., Montana. The first half of this reach is on tangent, while the second half is on a 20° curve around a gravelly point. On the tangent the bed of the canal is covered with fine sand in serrations from 1 to 2 feet longitudinally with the canal and about 6 inches deep. In the second half of the reach the sand covers the middle portion of the bed, while gravel up to cobble size forms the edges. The value of n found, 0.0226, is lower than is to be expected on this type of channel.

No. 180, Expt. S–40, Lateral No. 10, Orland project, United States Reclamation Service, California. Many of the conditions holding for this test are clearly shown in Plate XIII, figure 2. The gravel, most of which is under hen's-egg size, is well compacted in the bed of the ditch, while a few scattered patches of moss have a retarding influence. There were about two patches, each 5 feet in diameter, in each 100 feet of length down the ditch. Coefficient $n=0.0228$.

No. 184, Expt. S–39, main canal, South Orland project, United States Reclamation Service, California. This reach of earth channel (Pl. IV, fig. 3) lies just above the lined section tested in No. 51. It is straight, originally constructed in a yellow clay which is very slick when wet. A darker deposit of silt now covers much of this clay. A value of n of about 0.017 might be expected but for patches of moss and water grasses occupying about 20 per cent of the bottom of the channel. This influence brings about a value of 0.0231 for n.

No. 186, Expt. S–36, River Branch Canal, Sacramento Valley Irrigation Co., California. This ditch was originally excavated in Sacramento silty clay loam, which breaks into very hard small clods (Pl. XIII, fig. 3). The bed of the ditch was very slick and hard. A few scattered soft lumps of mud and a fringe of grass retarded the water and thorns extending out 1 foot raised the value of n from about 0.017 to 0.0236. Although the mean velocity is nearly 3 feet per second, there was no sign of scour in this hard soil. Coefficient $n=0.0236$.

No. 190, Expt. G–4, a small, new ditch in Louisiana. As shown in Plate XIV, figure 1, this ditch was practically as left by a plow, being but a week old. The reach is straight. Coefficient $n=0.0246$.

No. 192, Expt. S–88, Boulder and White Rock Ditch, Colorado. This reach tested on a small ditch with one bend (Pl. XIV, fig. 2). The original excavation was in meadow soil over river gravel. The bed contained graded gravel, mostly small but with a few cobbles of two-fist size. A dark silt had deposited in the lower velocities near the edges which were quite vertical, well-sodded banks. This ditch would be called in a good working condition as most of the stones were unavoidable. Coefficient $n=0.0248$.

No. 193, Expt. H–3, Billings Land & Irrigation Co., Montana. This reach (Pl. XIV, fig. 3) was originally excavated in Billings gravel. Silt has deposited in the low velocities at the sides, but the main bed is composed of gravel with cobbles up to two-fist size. The slight fringe of grass did not retard the main flow. Coefficient $n=0.0258$.

No. 194, Expt. S–23, a lateral of the South Side Twin Falls Canal, in Twin Falls, Idaho. Excavation for this ditch was through about 1 foot of lava-ash soil before striking hardpan. The present bed of the lateral is clean and hard as soft rock. A dense growth of sod and long grass retards the water at the vertical sides, and some silt has deposited on the edges of the bottom in the low velocities. The reach tested is shown in Plate XV, figure 1. Coefficient $n=0.0259$.

No. 195, Expt. H–1, Billings Land & Irrigation Co., Montana. A straight reach of canal excavated in gravelly soil was tested. The bed of the canal is of compact gravel up to one-fist size, while silt has deposited in the lower velocities near the sides. There is no grass in the water section. The mean velocity of the water encountered, 2.35 feet per second, appears to be sufficient to prevent the deposit of silt over the bed, though the water is very muddy. Coefficient $n=0.0259$.

No. 197, Expt. H–36, Bitter Root Valley Irrigation Co., Montana. The first two-thirds of the reach tested lies on a sidehill in hardpan, while the last third, originally constructed on a creek bottom, is now formed of sand drifts similar to those spoken of in No. 179. In the first part the hardpan is scoured clean except on inside of curves where sand has deposited, while lower down the ditch some cobbles are mixed with the sand. Coefficient $n=0.0260$.

No. 198, Expt. S–14, North Ogden Canal, Utah. This reach of canal follows a hillside contour about one-half mile below the mouth of Ogden Canyon. The material is composed of soil and rounded bowlders ranging from sand to several hundred pounds in weight. The sides were quite vertical and fringed with willow roots and grass, while a few patches of moss were scattered throughout the length of the reach. Aside from this moss this test would come under the class of cobble-bottom ditches, and the value of n 0.0262 is about right for such ditches.

No. 199, Expt. S–56, Main Branch Canal, Turlock Irrigation District, California. When tested this canal was carrying but a small part of its total capacity (Pl. XV, fig. 2). The water was so low that the influence of grass, which would have affected a deeper section, was lost. The bed was formed of hard-packed fine sand. The gentle curve shown in the view occurred between stations 5 and 7. Coefficient $n=0.0262$.

No. 200, Expt. H–4, Billings Land & Irrigation Co., Montana. A straight reach excavated in graded gravel up to two-fist size underlying about 1 foot of soil. The canal is nine years old. Mud has deposited in the slower velocities at the sides. Dense grass fringes the edge but does not trail in the water. Coefficient $n=0.0264$.

No. 202, Expt. S–8, Salt Lake City and Jordan Canal, Utah. This test was made on a reach of canal with one gentle curve in the upper end, but otherwise straight. Originally constructed in sandy soil with small gravel, the bottom now is very hard and

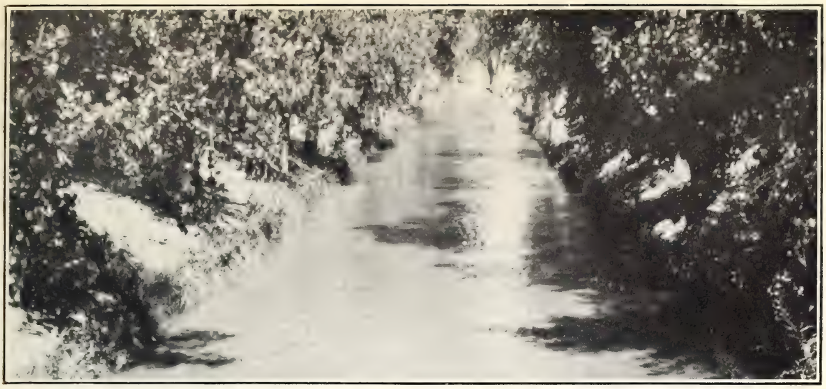

FIG. 1.—SALT RIVER VALLEY CANAL, UNITED STATES RECLAMATION SERVICE, ARIZONA.

(No. 175—Downstream from Station 5.)

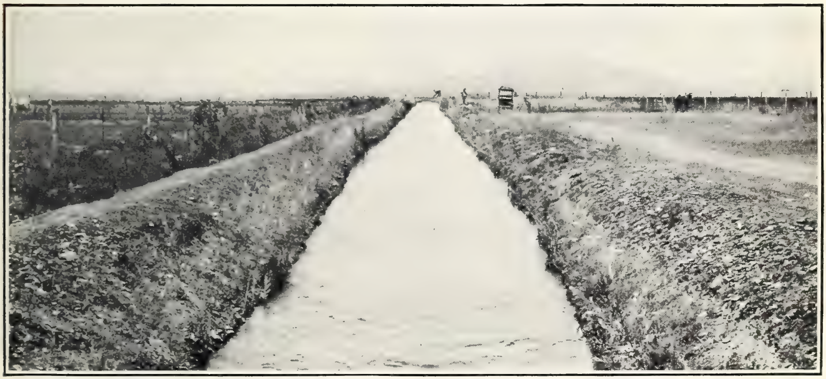

FIG. 2.—LATERAL 10. ORLAND PROJECT, UNITED STATES RECLAMATION SERVICE, CALIFORNIA.

(No. 180—Upstream from Station 5.)

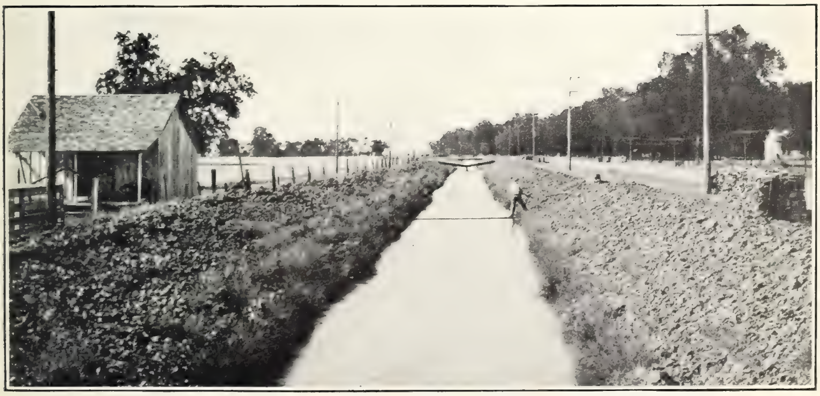

FIG. 3.—RIVER BRANCH CANAL, SACRAMENTO VALLEY, CALIFORNIA.

(No. 186—Upstream from Station 6. Station 0 below first bridge in distance.)

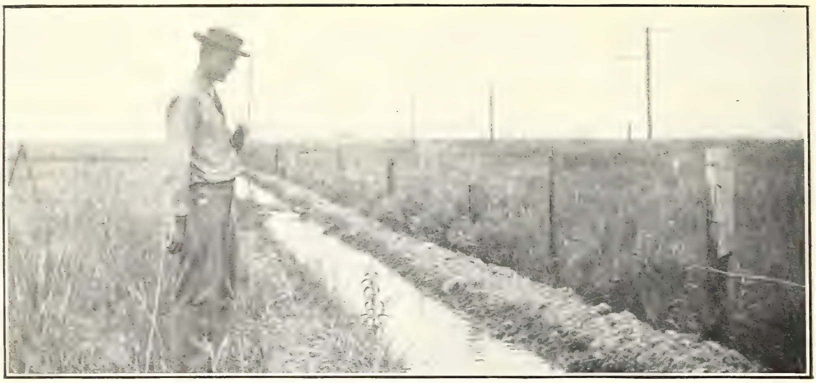

FIG. 1.—SMALL NEW DITCH IN LOUISIANA. (NO. 190.)

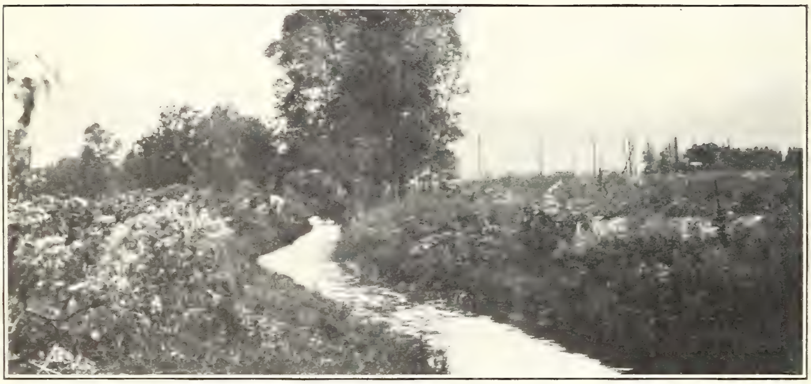

FIG. 2.—BOULDER AND WHITE ROCK DITCH, COLORADO.

(No. 192—Upstream from Station 2.)

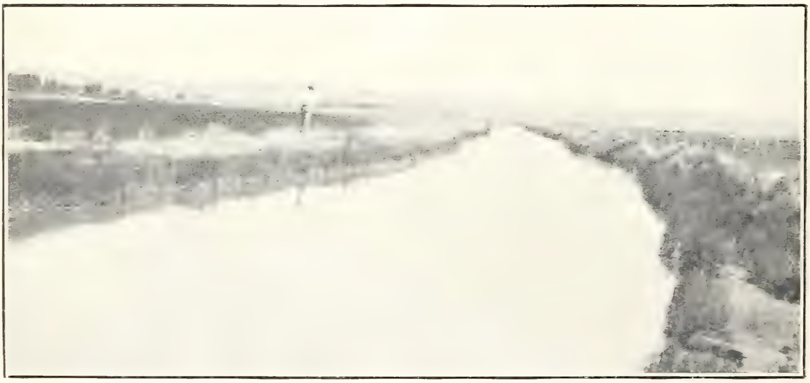

FIG. 3.—BILLINGS LAND & IRRIGATION CO. CANAL, MONTANA.

(No. 193—Upstream from lower end of reach.)

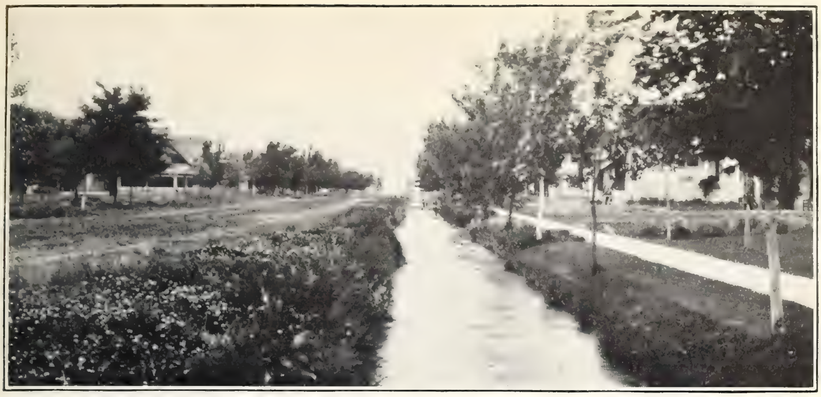

FIG. 1.—LATERAL, SOUTH SIDE TWIN FALLS, IDAHO.

(No. 194—Downstream from Station 0.)

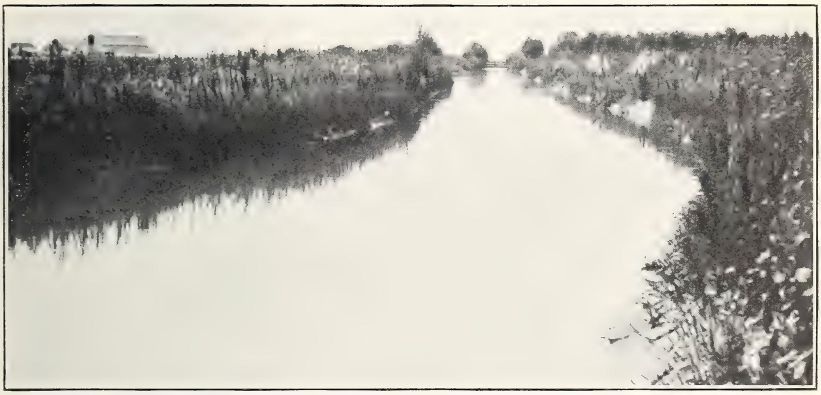

FIG. 2.—MAIN BRANCH, TURLOCK IRRIGATION DISTRICT, CALIFORNIA.

(No. 199—Upstream from Station 8.)

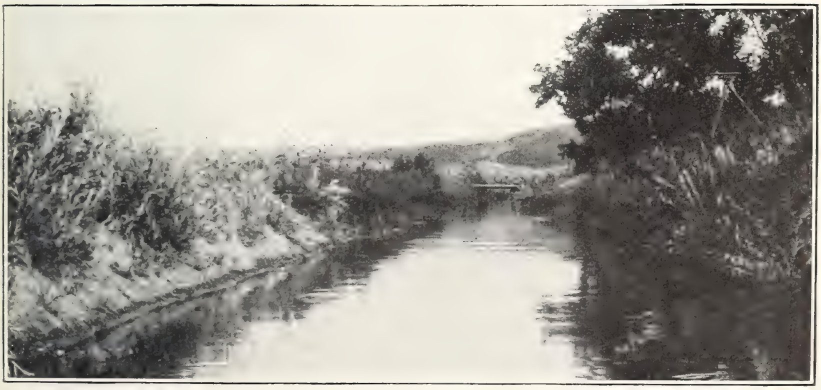

FIG. 3.—FULLERTON DITCH, CALIFORNIA.

(No. 204—Upstream from Station 5.)

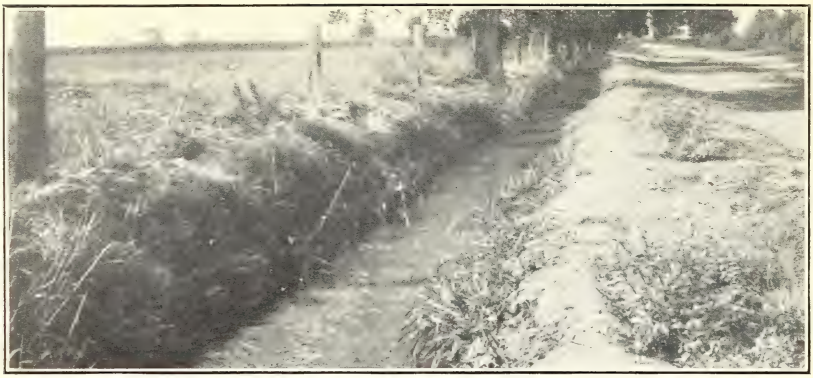

FIG. 1.—LATERAL 10. ARIZONA CANAL, UNITED STATES RECLAMATION SERVICE, ARIZONA.

(No. 213—Upstream from Meter Station 7.)

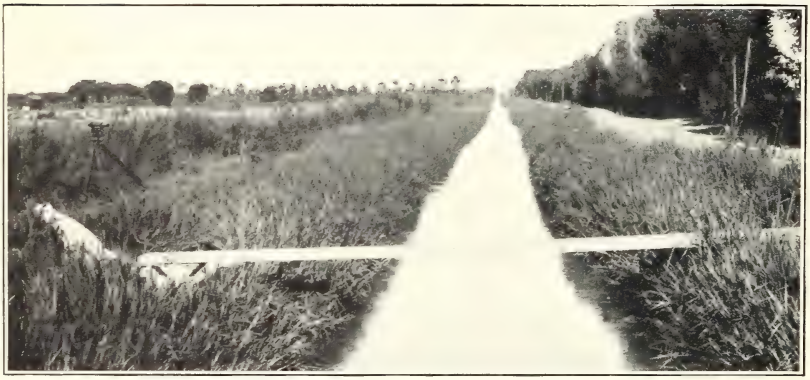

FIG. 2.—BEECH CANAL, IMPERIAL VALLEY, CALIFORNIA.

(No. 215—Upstream from Meter Station 10.)

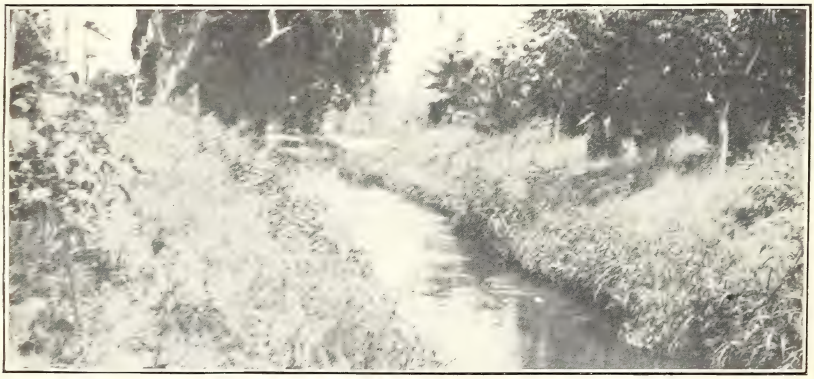

FIG. 3.—LOWER CANAL, RIVERSIDE, CAL.

(No. 224—Upstream from Station 2.)

cemented except at the sides, where the velocity (mean 1.57 feet per second) is not sufficient to prevent silt from depositing. A dense growth of grass killed the velocity for about one-half foot from the banks, which were quite vertical and are typical of the old ditches in Colorado and Utah. Coefficient n=0.0267.

No. 204, Expt. S–66, Fullerton Ditch of the Anaheim-Union Water Co., California. Station 0 of the reach tested is at the lower end of a gentle curve (Pl. XV, fig. 3), while about 100 feet below station 6 there is an angle of about 80° to the right which checks up the water so that a correction for change in velocity head was necessary in computing the value of n. Grass and moss kill the velocity for about 1 foot from the banks, while the bed of the canal is a hard, cemented, sandy loam soil, with about 0.1 foot of shifting sand. This canal was under exactly the same conditions as No. 172, except that this needed cleaning and the other one had just been cleaned. The difference in value of n is about what should be expected and shows the value of cleaning. Coefficient n=0.0269.

No. 205, Expt. S–86, Farmers' Canal, near Boulder, Colo. When tested this ditch was carrying about half its capacity. It is constructed along a gently curving hillside. Willows and grass form a dense fringe at the sides, while the bottom, originally constructed in red mountain soil mixed with fragments of sandstone, now has a rather hard, gravelly bottom, with angular fragments rather than rounded pebbles. The section is irregular, and the value of n is quite comparable with that of a cobble-bottom ditch, although this reach is not cobble bottomed. Coefficient n=0.0270.

Nos. 206, 207, and 208, Expts. H–12 a, b, and c, lateral 2, Billings Land & Irrigation Co., Montana. These tests are on an irregular section of small lateral, constructed in loamy earth. It is now fringed with grass, which trails somewhat, though newly mowed. The discharge was varied for the various tests. The bottom is irregular, with drifting sand throughout most of the reach. The canal is too irregular to concede too much weight to the various values of n found.

No. 209, Expt. S–60, Yosemite Power Co.'s Ditch. This ditch follows a mountain contour in disintegrated-rock soil. A fringe of bushes and grass retard velocity at the banks, while the bottom is porous and gravelly with scattered bowlders and rock fragments up to two-fist size. The value of n is about what may be expected of a cobble-bottom ditch, although this one does not strictly class as such. Coefficient n=0.0274.

No. 210, Expt. S–5, lateral of Parley's Ditch, Utah. This test is on a straight reach in gravelly loam soil. A fringe of grass retards velocity for about one-half foot from the banks. The bottom is composed of clean sand which yields about 0.1 foot to the feet, in wading. A slight wind upstream makes the value of n a little high. Discounting the wind, this value would be about that of test No. 209 above. Coefficient n=0.0278.

No. 212, Expt. S–20, lateral of South Side Twin Falls Canal, Idaho. This reach of ditch is on a gentle contour curve of about 400 feet radius. Constructed in hardpan underlying about a foot of lava-ash soil, the water section is quite slick but is badly washed in longitudinal gullies. The banks, too, are irregular and fringed with a dense growth of grass and alfalfa. Coefficient n=0.0283.

No. 213, Expt. S–85, lateral 10 from Arizona Canal, Salt River project, United States Reclamation Service, Arizona. This test is on a straight reach of small ditch on a steep grade. Constructed in a silt loam soil, the high velocity has washed very irregular gullies and pockets. An average growth of grass and weeds also retards velocity. (See Pl. XVI, fig. 1.) Coefficient n=0.0284.

No. 215, Expt. S–79, Beech Canal, Imperial Water Co. No. 1, California. This test is under exactly the same conditions as those described in No. 162, with the exception that a longer time has elapsed since the dense growth of grass shown on Plate XVI, figure 2 was cut. The difference in grass condition is noted by comparing the above view with that in Plate XI, figure 2. Coefficient n=0.0290.

No. 216, Expt. S–49, Wheeler Ditch, Nevada. This test was made on a ditch following a contour in curves of from 300 to 500 feet radius. While the bottom is hard many bowlders of several hundred pounds weight border the channel, and a few have rolled into it. A dense growth of grass and bushes fringe the sides, and a fine, dense moss retards velocity for about 0.3 foot from the bottom. Coefficient n=0.0292.

Nos. 219 and 220, Expts. H–13c, lateral of Billings Land & Irrigation Co., Montana. These tests were made on the same reach of canal but with varying discharges, and for No. 219 grass fringing the edges was cut, hence removing some of the retarding influence present in No. 220. The bottom is covered with fine, deep, shifting sand, so "quick" that a wading man sinks about 1 foot.

No. 221, Expt. S–59, main canal, Modesto Irrigation District, California. This test was made on a wide canal with but a small portion of its total capacity running. This gave a condition of shallow water flowing over gullied hardpan having about 0.1 feet of shifting sand. No grass touched the water at this stage. Coefficient n=0.0300.

No. 222, Expt. S–72, Upper Canal, Riverside Water Co., California. This test was on a straight reach of canal originally excavated in a sandy loam soil. At present the bottom is covered with a bed of fine sand which remains quite hard until disturbed, when it cuts rapidly. Dense grass along the sides and scattered patches of moss in the canal cause a high value of n. Coefficient n=0.0315.

No. 223, Expt. S–77a, Lower Canal, Riverside Water Co., California. Though originally excavated in a clean-cut section of soft hardpan, the present condition of this reach is much less efficient, due to a deposit of shifting sand and growths of water grasses and dense grass along the edge, though not so bad as in No. 224 below. Coefficient n=0.0318.

No. 224, Expt. S–77b. Same canal as No. 223 above, but the grass along the edge kills velocity for about 1 foot from both banks. Otherwise the same general condition holds as before. This reach adjoins the other reach at a right-angled bend shown in Plate XVI, figure 3. Coefficient n=0.0360.

No. 228, Expt. S–9, Lower Canal from Big Cottonwood Creek, Utah. This test was made on a ditch which would have an efficient carrying capacity with a small amount of labor, but through neglect willow roots and grass have so encroached on the channel that a high value of n is obtained. Originally constructed in a sandy loam soil, the bottom was quite hard with no cobbles but with a deposit of soft mud in the lower velocities near the sides. The reach tested is on a gentle contour curve, which exerts an inappreciable influence when compared with the vegetable growth. The banks are quite vertical and irregular, like most rooted channels. Coefficient n=0.0324.

No. 230, Expt. S–62, Golden Rock Ditch, Yosemite Power Co., California. This reach tested follows a gentle mountain contour. The bottom is of clean disintegrated slate with scattered pieces to two-fist size. Although this bottom has a great retarding influence, the value of n is higher than is to be expected. There was but little grass touching the water. Coefficient n=0.0346.

No. 231, Expt. H–15, lateral 1, Billings Land & Irrigation Co., Montana. This reach of ditch is in sandy loam fill. The water section is irregular with sand in the bottom and a little trailing grass and moss. Coefficient n=0.0349.

No. 233, Expt. S–18, Logan and Hyde Park Canal in Logan, Utah. This straight reach of canal (Pl. XVII, fig. 1) was originally constructed in gravelly soil with many cobbles from egg to two-fist size. At the time of the test the edges were irregular and densely grassed, with patches of moss and some cobbles scattered throughout the reach. The moss lies usually within 0.3 foot of the bottom. Coefficient n=0.0364.

No. 235, Expt. S–53, lateral 2½, Turlock Irrigation District, California. This test is a straight reach of canal excavated in hardpan requiring blasting. This leaves the section rough and pitted. The bottom was covered with about 3 inches of rough, gritty sand. As the canal was only about one-half full, no grass touched the water at the time of the test. Coefficient n=0.0373.

No. 236, Expt. S–42, Cochrane Ditch, Nevada. This ditch is constructed in gravelly soil with many cobbles. The test was made on a reach having one bend (see Pl. XVII, fig. 2). The bottom had many loose cobbles scattered on an otherwise hard gravel bed. The banks throughout nearly all of the reach tested were overhung with densely grassed sod. In addition about 20 per cent of the water section was occupied with moss. Coefficient n=0.0379.

No. 237, Expt. S–25, Perrault Canal, Capital Water Co., Boise, Idaho. This ditch (Pl. XVII, fig. 3) constructed in gravelly loam soil, has a very hard cemented bottom. A dense growth of grass so kills the velocity for a distance of about 1 foot from each bank that the value of n is very much greater than would be the case if the canal were kept free from this growth. Coefficient n=0.0381.

No. 239, Expt. S–46, Orr Ditch, in Reno, Nev. The reach tested passed in a horseshoe curve around the small lake on the university campus. It was originally excavated in loamy soil with a little gravel. At time of test the bed was clean scoured, but near the sides a man wading sank about 4 inches in soft mud. Dense grass and willows retard the velocity at both banks, while the water section is very irregular throughout the reach. Coefficient n=0.0397.

No. 240, Expt. S–21, a small ditch in Twin Falls, Idaho. This is a small ditch with grass arching across in many places. Originally constructed in hardpan, the reach is irregular with scattered débris such as is so often found in town ditches. Coefficient n=0.0399.

No. 241, Expt. S–52, Capurro Ditch near Reno, Nev. As shown on Plate XVIII, figure 1, this is a small ditch thickly fringed with grass and with scattered cobbles in the bottom. The banks are quite vertical, densely rooted, and very irregular. The bottom is covered with about 0.1 foot of soft mud through which the scattered cobbles project. Coefficient n=0.0403.

No. 243, Expt. S–4, New Rutner Ditch, Nebraska. This ditch follows a gentle contour line down a creek bottom. At time of test the ditch had a very hard bottom of medium-fine gravel, well packed, but a dense growth of grass killed the velocity for about one-half foot from each bank, and scattered patches of moss retarded that in the middle. The banks of the ditch are very irregular. Coefficient n=0.0436.

No. 244, Expt. S–44, Sullivan and Kelly Ditch, Nevada. This test was made on a ditch excavated in a gravel and cobble hillside. At time of test the bottom was hard-packed gravel in the center with a slight deposit of soft mud at the sides. Scattered cobbles and a dense growth of grass retarded the velocity of the water. The reach follows a gently curving contour line with one right-angled bend near the lower end of the reach tested. Coefficient n=0.0436.

No. 245, Expt. G–2, Roller Canal, Louisiana. This test was made on a straight reach of canal. The vegetation shown in Plate XVIII, figure 2, extended for about 5 feet from each shore. Coefficient n=0.0461.

No. 249, Expt. G–5, a small ditch in Louisiana. This ditch was chosen as representative of the small ditches in the rice country. Grass extended from one bank to the other across the bed of the ditch, occasionally growing to the water surface from the bottom of the ditch. The grass forms a dense mat in the bottom. The grass had been cut with a scythe about one week before the test. Coefficient n=0.0544.

COBBLE-BOTTOM DITCHES.

No. 251, Expt. H–31, Bitter Root Valley Irrigation Co.'s Canal, Montana. This test was made on a nearly straight reach 600 feet long, excavated in very gravelly ground with bowlders up to 2 cubic feet in size. The first third of the distance fairly smooth on the bottom with no stones larger than two-fist size; upper slope cobbly and with some grass on the lower water edge. Second third of distance much roughness, with cobbles over most of bottom. Last third, in condition intermediate first and second thirds. Coefficient n=0.0262.

No. 252, Expt. S–10, Upper Canal from Big Cottonwood Creek, Utah. This reach of canal follows a gentle contour curve on a very gravelly hillside. The sides are nearly vertical and lined with trees and willows whose rootlets extend into the water prism. The bottom is completely covered with cobbles up to two-fist size. Like nearly all ditches of this character the sides are irregular in outline, as the cobbles do not break into an even bank. Coefficient n=0.0277.

No. 253, Expt. S–15, Logan and Northern Canal, Utah. This is a fine example of a ditch following a gravelly hillside contour near the mouth of a canyon, a condition typical of many canals near the mountains. The sides are densely fringed with willows and bushes whose rootlets hold silt and form nearly vertical banks. The bottom is completely covered with well-packed gravel and cobbles up to two-fist size. Coefficient n=0.0270.

No. 254, Expt. S–51, Reno Ditch of the Reno Light & Power Co., Nevada. This reach of canal was originally excavated in an old river bed containing innumerable bowlders up to 5 cubic feet in size (Pl. XVIII, fig. 3). About a year before this test the sides and bottom of this channel had been paved with a hand-laid riprap of these bowlders, the sides being laid about ½ to 1, and the bottom flat. Many of the bowlders at the top of the walls have rolled into the canal, as no cement or other bond was used, but the general condition of the walls appears to be good. The reach tested was straight with the exception of a gentle curve in the last 200 feet. Coefficient n=0.0291.

No. 255, Expt. S–43, Sullivan and Kelly Ditch, Nevada. This reach follows a gentle contour on a rocky hillside (Pl. XIX, fig. 1). The bowlders have been hand laid in a nearly vertical wall on the lower side while the bottom and upper side are rough and irregular with projecting large bowlders. A slime of mud from the Truckee River water covers all rocks below the water line. Vegetation is negligible. Coefficient n=0.0324.

No. 259, Expt. S–89, Beasley Ditch, Colorado. This canal on a straight reach with a curve about 100 feet below the lower end. At the time of test it was carrying but about one-fourth its capacity. The bottom and sides are a mass of unpacked gravel and bowlders up to 2 cubic feet in size. Coefficient n=0.0383.

SIDEHILL CUTS, WITH RETAINING WALLS.

No. 261, Expt. H–23, Hedge Canal, Montana. This test was made on a short reach excavated in granite hillside, with the lower bank formed of a random rubble masonry wall, well plastered with mortar on the nearly vertical water face. The reach is straight except for a slight curve in the last 50 feet. The bottom is covered with granite gravel, most of which would pass a ½-inch screen, with occasional pieces one-fist size. The excavation is quite true to line for a rock cut. Coefficient n=0.0185.

No. 262, Expt. H–27, Hedge Canal, Montana. This reach is about 500 feet below that in No. 261. The upper side is excavated quite true to line in earth and disintegrated granite. The lower side is a vertical concrete wall laid against board forms. The floor is concrete with from 1 to 2 inches of fine, sharp ravelings from the hillside. In scattered spots the floor shows. The reach is 450 feet long. Station 1 to 2 is about a 20° curve, on 12-foot chords. At station 3+40 is a rather sharp bend. The rest is fairly straight. Coefficient n=0.0225.

No. 263, Expt. H–9, Cove Ditch, Montana. This reach is cut from a sandstone hillside (Pl. XIX, fig. 2). The lower bank is a rubble masonry wall plastered with concrete on the water side. The bottom is also overlaid with concrete. The alignment is wavy with some 20° curves. From stations 0 to 2 there is some gravel; from stations 2 to 4, clean bottom, the rock on upper bank being smooth but the width

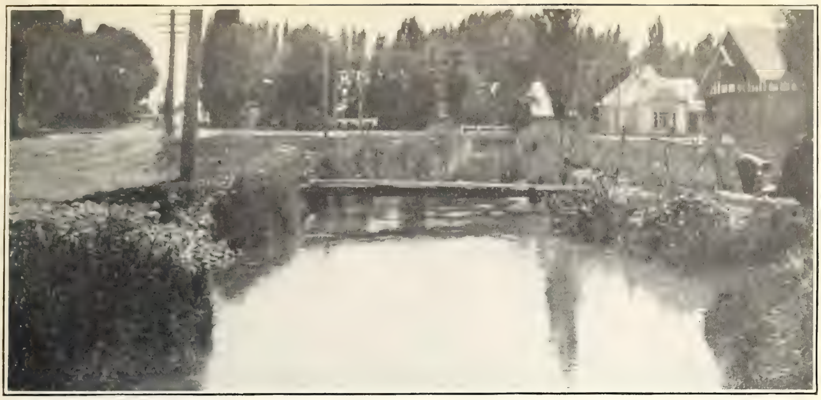

FIG. 1.—LOGAN AND HYDEPARK CANAL, UTAH.

(No. 233—Upstream from Station 2.)

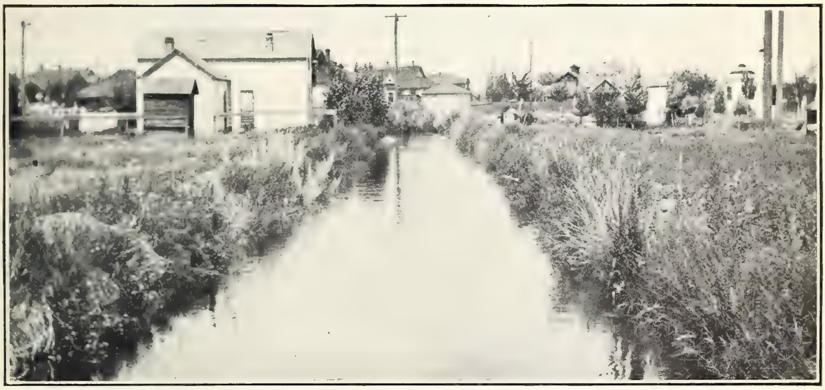

FIG. 2.—COCHRANE DITCH, RENO, NEV.

(No. 236—Upstream from Station 5.)

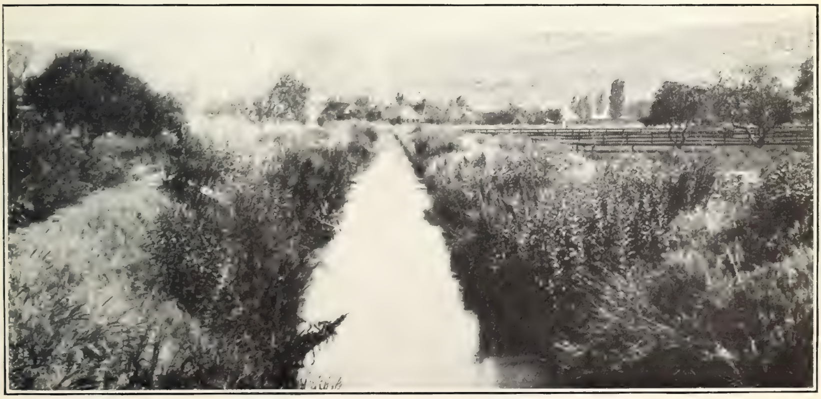

FIG. 3.—PERRAULT CANAL, BOISE, IDAHO.

(No. 237—Downstream from Station 0.)

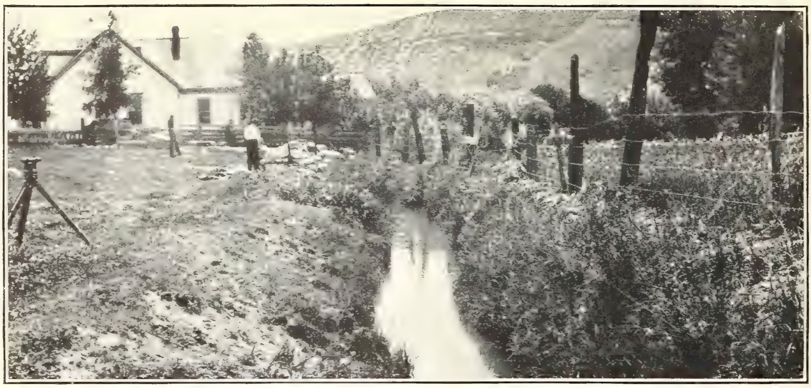

FIG. 1.—CAPURRO DITCH, NEVADA.

(No. 241—Downstream from Station 1.)

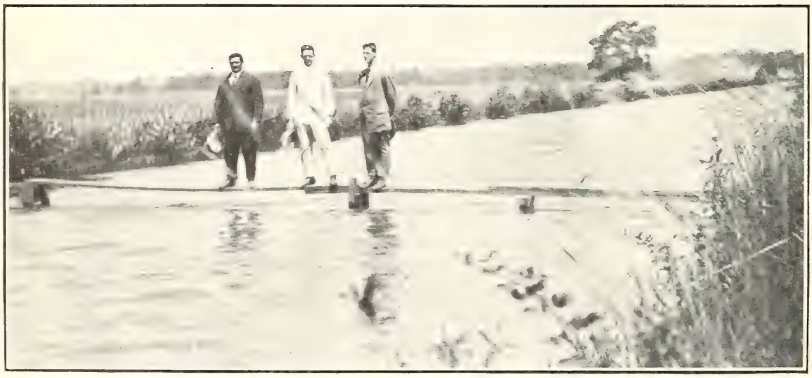

FIG. 2.—ROLLER CANAL, LOUISIANA.

(No. 245—Showing meter station.)

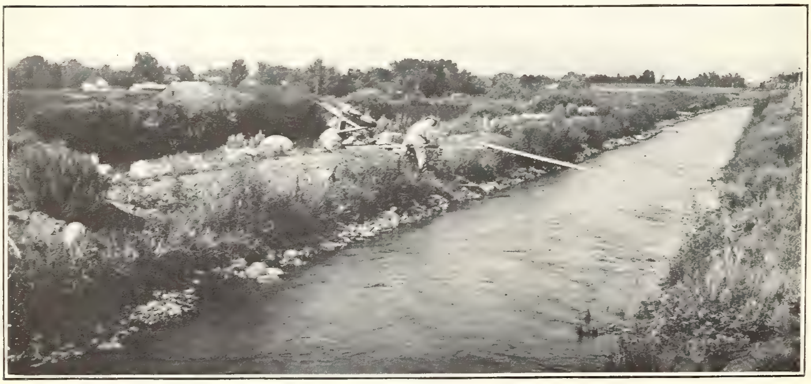

FIG. 3.—RENO DITCH, NEVADA.

(No. 254—Downstream from Station 0.)

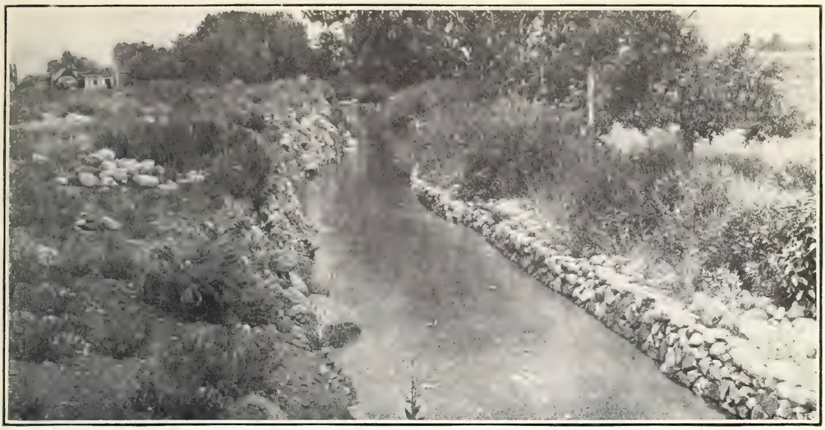

FIG. 1.—SULLIVAN AND KELLY DITCH, NEVADA.
(No. 255—Downstream from Station 1.)

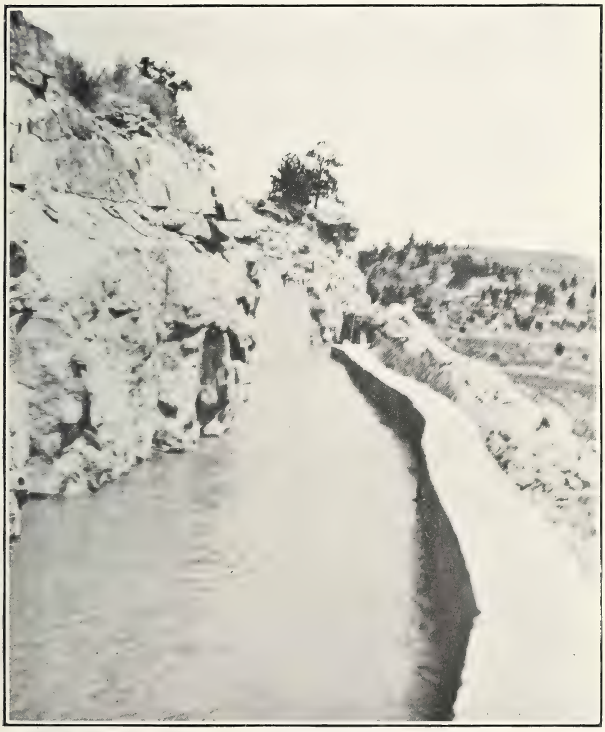

FIG. 2.—COVE DITCH, MONTANA. (No. 263.)

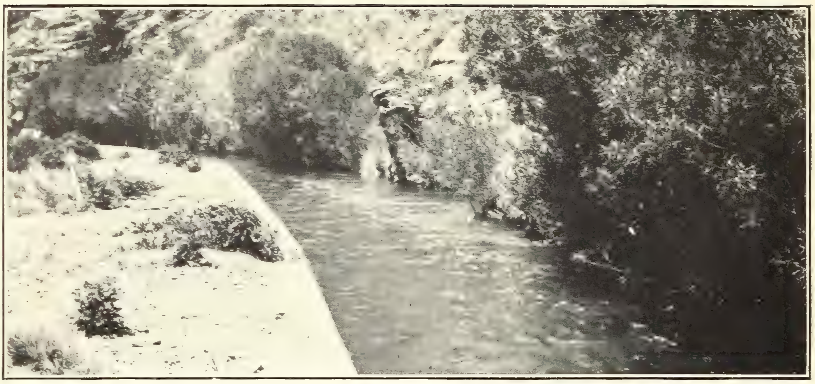

FIG. 1.—LOGAN, HYDEPARK, AND SMITHFIELD CANAL, UTAH.

(No. 264—Downstream near lower end of reach.)

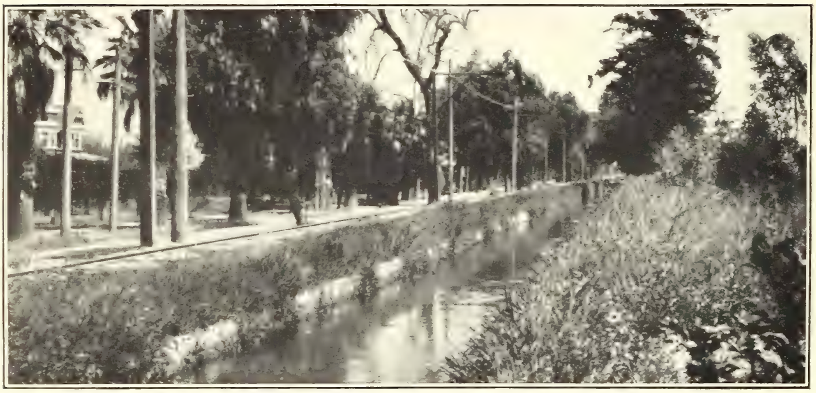

FIG. 2.—LOWER CANAL, RIVERSIDE, CAL.

Note plank lining. (No. 268—Upstream from Station 6.)

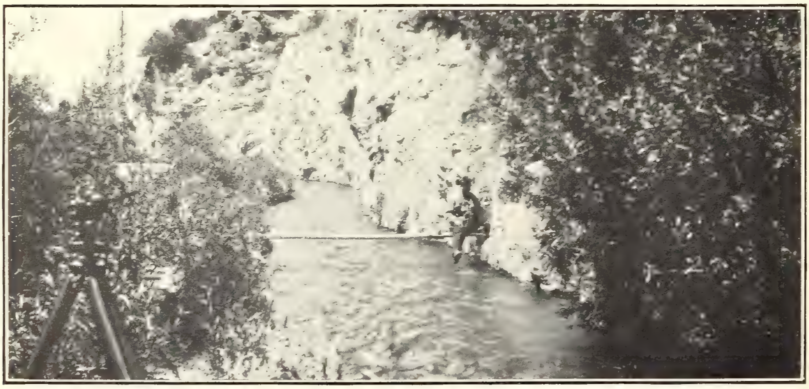

FIG. 3.—LOGAN, HYDEPARK, AND SMITHFIELD CANAL, UTAH.

(No. 269—Downstream past meter station.)

irregular; from stations 4 to 6, more uniform in width but rough on rock side; from stations 6 to 7, rock wall is rough and width variable; from stations 7 to 8, rock wall quite smooth, bottom clean or little gravel, the width uniform. Coefficient n=0.0228.

No. 264, Expt. S–17a, Logan, Hyde Park and Smithfield Canal, Utah. This test made on a reach 337 feet long between an earth section and the reach in No. 266 below (Pl. XX, fig. 1). The excavation is on a steep hillside. The upper bank is mostly of willow roots, while the lower bank is a well-made concrete wall. The bottom is covered with coarse gravel. This reach is nearly straight with bends at both ends. This is classed as B rating by reason of these bends. Coefficient n=0.0256.

No. 265, Expt. H–26, Hedge Canal, Montana. This reach is excavated in rock cut with concrete floor and a rubble masonry lower wall, faced with 3 inches of concrete, deposited against wood forms. The bottom is mostly covered with sand and ravellings of small rock. The upper bank is rough rock excavated quite true to cross section. The alignment is practically straight except for one sharp curve between stations 0+80 and 1+50. The value of n is higher than in No. 262, which has a smoother section. Coefficient n=0.0269.

No. 266, Expt. S–17b, Logan, Hyde Park and Smithfield Canal, Utah. Just below the reach described in No. 264 the canal enters the section covered in this test. The same concrete wall formed the lower bank, and the bottom was about the same, but the upper bank is a rough vertical rock cut. The difference in the value of n is about what is to be expected. Coefficient n=0.0278.

MISCELLANEOUS SECTIONS.

Nos. 267 and 268, Expts. S–74 and S–73, lower canal, Riverside Water Co., California. These tests made on a straight reach of canal in a sandy soil with a shifting sand bottom and a wood lining on the lower side (Pl. XX, fig. 2). The canal in test No. 267 is in the shade of a dense row of trees and is free from moss accumulations. Coefficient n=0.0249.

The canal in test No. 268 is in the sun and moss has accumulated on the wood lining. Coefficient n=0.0291.

In both tests the water was retarded by a rank growth of grass for about 1 foot from the bank opposite the wood lining. The difference in the values of n is directly due to the moss which grows in sunlight and does not in shade.

No. 269, Expt. S–17c, Logan, Hyde Park and Smithfield Canal, Utah. This reach is fairly straight, excavated in rough rock. The bottom is strewn with coarse gravel (Pl. XX, fig. 3). Coefficient n=0.0298.

THE USE OF VALUES OF *n*.

The engineer is required to exercise his judgment as to the value of n in two general ways:

1. The value to be substituted in the formula in the design of a channel or in the changing of a channel from one containing material to another.

2. The value that is to be used when the engineer is called upon to determine the maximum carrying capacity of a canal already constructed but at the time of inspection carrying no water or but a small portion of its capacity.

In the design of channels it has been customary to allow little or no factor of safety. In the opinion of the writer it is as necessary to allow for a slight overload in a canal as in any other conservative construction. This should be accomplished by choosing as nearly as possible the correct value of n and then designing for whatever overload is deemed conservative. Another method which is sometimes followed is to choose a relatively high value of n and then design for the desired discharge. This method is not to be recommended and in some cases may be even dangerous for the reason that the velocity may so increase beyond a safe figure for the containing material that the canal can be eventually operated at but a part of its designed capacity. This fact is brought out in the case of a prominent canal in western Nebraska. A value of n of 0.025 was chosen as applying to such a canal in a moderate state of operative efficiency. As determined by numerous experiments, the material cemented into a smooth, hard canal bed with an efficiency almost equal to concrete; that is, n is actually about 0.016, and when operated to about one-half its depth the velocity becomes so high that there is great danger of scouring the channel. Thus a large portion of the excavated area of the canal can not be used unless lined with some material which would withstand scouring or else checks installed to reduce the grade. Had the correct value of n been chosen at the time of construction, the slope might have been far less than it is and additional territory made irrigable or a different-shaped cross section might have been chosen which would have had about the same yardage per given length and the same ultimate carrying capacity as was desired for the present canal.

In the second case cited above, where the engineer must estimate the carrying capacity of a canal already constructed, there is room for divergence in the estimates of two men equally competent and using data collected under the same conditions.

If the canal is carrying its capacity at the time of inspection the results of two men should agree quite closely, as it is a mere matter of making a discharge measurement.

If the canal is about half full a careful measurement may be made similar to the ones for the experiments described in this publication. From this experiment the value of n holding for the given condition may be determined. If the canal is straight and there is no influence from structures it may be safely assumed that the surface slope will remain quite constant up to capacity. Any material change in the value of n must be determined by the influence of the two banks above the surface of the water flowing at the time of test. A clean concrete, wood, or steel channel will have a slightly lower value of n. An earth channel rarely has the same character of material throughout the length of the wetted perimeter, and due allowance must be made for changes.

This involves the judgment of the engineer, and two men will disagree more or less at this point. The general elevation of where the water surface will be when the canal is full is another place where the estimates of two men will separate. The lines of levels run by the two may develop slightly different critical points in the canal bank at which the canal would overflow. The depth of freeboard between the capacity water surface and the lower bank profile will probably differ. The controlling cross sections will not necessarily agree.

If the canal is dry at the time of inspection, then the solution of the problem as to the capacity is further complicated by the fact that no test can be made to determine the value of n, and the judgment alone must be relied on as to the correct value. The surface slope is also indeterminate, and a grade line through the controlling points of the profile of the canal bed must be assumed as the slope. This value also will be different in two estimates.

In the courts of law of the Western States many attorneys and judges have come to regard as the last word a statement to the effect that the capacity of a canal has been computed by Kutter's formula. While the algebra of the formula is an exact science and exactly the same answer will be obtained by several parties if the same hydraulic data, including the value of n, are assumed, the fact remains that the assumption of the value of n may be largely a matter of judgment, and the results of two men should not be discredited merely for the reason that they disagree slightly.

RECOMMENDATIONS FOR VALUES OF n FOR DIFFERENT KINDS OF CHANNELS.

Either in the design of canals or the determination of the carrying capacity the material forming the perimeter divides into the following general classes: 1, concrete lining; 2, wooden flumes; 3, metal flumes; 4, masonry lining; 5, earth canals; 6, cobble-bottom canals; and 7, sidehill cuts with retaining walls. There are a few special cases that do not come under any one of the classes mentioned, but a proper comparison can be made by assuming parallel conditions.

The following values are applicable for velocities up to about 5 feet per second and with hydraulic radii up to about 2 feet. If velocities and radii are greatly to exceed the above figures, slightly lower values of n should be used.

VALUES OF n FOR CONCRETE LINING.

I. $n=0.012$ for the highest grade of material and workmanship and exceptionlly good conditions. The surface of the lining to be as smooth to the hand as a troweled sidewalk. The expansion joints to be so well covered that they practically fulfill the same condition. The climate and water to be such that moss does not accumulate to any great extent. The water to be practically free from shifting material. The alignment to be composed of long tangents joined by spiraled curves, while the interior of the channel must be of uniform dimensions, true to grade throughout the cross section.

II. $n=0.013$ for construction as in type I, but with curves as in the usual mountain canyon. Same construction and alignment as in type I, but with small amount of sand or débris in water. Construction as in type III, but in very favorable alignment or for water that carries a small amount of fine silt that will eventually form a slick coat.

III. $n=0.014$ for linings made by good construction under favorable conditions. The surface to be as left by smooth-jointed forms or to be roughly troweled. Joints to be good, but causing some retardation. Alignment about equal in curves and tangents, with no spirals between. The bed to be clean and sides free from rough deposits. In the opinion of the writer this is the value to use for most linings on moderate-sized channels.

IV. $n=0.015$ for construction as in type III, but with sharp curves and clean bottom or moderate curves and much débris on the bottom but clean-cut sides.

V. $n=0.016$ for concrete as constructed by the average gang of laborers, using forms that leave prominent lines at the cracks, no finish coat being applied. Bed to have the usual small amount of rock fragments and patches of sand and gravel. Average amount of curvature. In climates where a rough deposit accumulates, as in southern California, a lining that originally had a value of n about 0.013 quickly assumes about this type. For this reason it appears to the writer that labor and money spent in securing a very smooth surface is lost where the deposit accumulates on smooth or rough alike.

VI. $n=0.017$ for roughly coated linings with uneven joints. This value also is applicable where rough deposits accumulate on the sides and conditions of alignment are poor.

VII. $n=0.018$ for very rough concrete with sharp curves and deposits of gravel and moss. A broken gradient, irregular cross section, and the like, contribute to such a high value of n.

Where experiments show higher values of n than are given above for concrete linings, the conditions are such, as a rule, that the containing material has lost its identity as concrete or cement, and thick coatings of sand, accumulations of moss, or deposits of sand change the general classification of the channel.

VALUE OF n FOR WOODEN FLUMES.

While experimental flumes have been constructed that showed values of n in the neighborhood of 0.009, yet in making tests on flumes in commercial service values of n below 0.012 are so rare that it is not thought advisable to recommend any value less than this. Wood is subject to so many changes, due to the influences of climate, wind, settling of earth, moss accumulations, warping, and so on, that even when well constructed the value of n becomes greater after a few months' use than when new, and it is better to use a value of n that will hold for the greater part of the life of the flume.

The above statements apply to the ordinary plank flume. Where staves are used which is quite rare since the advent of the steel flume, a lower value will probably hold throughout the life of the flume, for its very construction is such that it must stay in quite good condition or fail, due to the compression existing between the edges of the staves. In many cases the designer of a flume considers only the lumber, battens, and calking, while in actual practice the good influences of well-chosen materials are often completely lost through the accumulation of rock fragments, gravel, and so on. A very common location for a flume is down a bench cut in a rocky hillside. Whenever the cut is such that the fragments sloughing from the hill would fall into the flume, care should be exercised to keep the flume out from the side of the cut, or a guard wall should be constructed to divert débris so it will fall back of the flume. If high velocities are constantly to be maintained, ordinary dirt and small stones will roll on down the flume or accumulate on the inside of sharp curves. Short flumes are quite liable to take about the same value of n as the earth section above, as the same bottom becomes characteristic of both.

I. $n=0.012$ for well-constructed, clean flumes with surfaced lumber for both siding and battens. All lumber to run longitudinally. Alignment to consist of long tangents with gentle curves between. Construction to be such that the grade line will remain uniform, preventing sags and wavy alignment. A flume without battens may have a very slightly lower value of n, but this difference will be inappreciable if the added length of the wetted perimeter due to the battens is considered in the design. Some very smooth grades of roofing materials used as linings also give a slightly lower value of n, but not enough to consider. If flumes are calked with oakum or other stuffing, care must be used that none projects into the water section if a high degree of efficiency is to be maintained.

II. $n=0.013$ for well-constructed, clean flumes of surfaced lumber and battens, following mountain contours, where the alignment will consist of about equal gentle curves and tangents. This value will also apply to flumes with alignment and grade as described in type I, but with vertical battens at intervals, with projecting calking or a slight amount of hardened asphalt or other waterproofing retarding the velocity.

III. $n=0.014$ for flumes of very smooth interior, but with many bends or sharp curves. This value also applies to those of type I with a location such that a slight amount of hillside débris is unavoidable. Construction of type I, but with cracks poured with any waterproofing material that hardens in tapering drops, is also liable to come in this type. For type I except that unsurfaced lumber is used.

IV. $n=0.015$ for flumes of unplaned lumber, but otherwise as of type II. In the opinion of the writer this is about the value to use for the usual grade of construction in a mountain canyon where the flume will get about the usual grade of maintenance with repairs made with irregular-shaped scraps of boards.

V. $n=0.016$ for flumes of type IV where sharp bends rather than curves are installed. For flumes lined with rough roofing material and for the ordinary grade of construction on a flume that is built and generally left to care for itself. The kind of an organization that is to operate the flume will determine this factor.

For values of n higher than 0.016 the inside of a flume has changed so that its character as a wooden flume is practically lost. Débris accumulations, warped and loose battens, excessive sagging, with consequent accumulation of débris, all contribute to make values above 0.016 rather indeterminate, except by actual test.

VALUES OF n FOR METAL FLUMES.

As noted in a bulletin of the Colorado Agricultural Experiment Station,[1] metal flumes are divided into three clean-cut groups.

Group 1. Those having countersunk joints between the various sheets of metal so that there is practically no added roughness presented to the water.

Group 2. Those having joints that project into the water section presenting a shoulder every few feet that effectually retards the velocity. This type is not installed to any great extent at present, but there is a great deal of it in actual use, as it was the pioneer in steel fluming.

Group 3. Those having regular corrugations at right angles to the axis of the flume. This makes a stiff flume, not so liable to sag, but with a rather high value of n.

I. $n=0.011$ for flumes of group 1, in favorable alignment and clean.

II. $n=0.015$ for flumes of group 2, in favorable alignment and clean.

III. $n=0.022$ for flumes of group 3, in favorable alignment and clean.

This value is based on but one observation, by Mr. Cone.

Where flumes are short, they are liable to accumulate the same class of detritus in the bottom as the section above them. Where the possibility of débris accumulations exists it should be considered in design.

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[1] Colorado Sta. Bul. 194.

VALUES FOR *n* IN MASONRY-LINED CHANNELS.

The writer has not sufficient tests on masonry-lined sections to make suggestions as to specific values of n to use, but the following general observations seem to be warranted:

As a rule the proportion of the wetted perimeter extending across the bottom far exceeds that on the two sides; therefore the preponderance of influence comes from the bottom. If this be of smooth concrete and the sides are reasonably smooth, then the value of n approximating that in average concrete may be used. If the sides are unchinked, they will be rougher than the sides of the average earth canal, but again the bottom must be given the most weight.

VALUES OF *n* FOR EARTH CHANNELS.

The value of n in earth channels extends over a far greater range than in any other material. More complex conditions, more permutations and combinations of conditions exist than are possible in a channel that reasonable velocities can not erode. If kept clean, concrete, wood, or steel must maintain about the same cross section; as a rule, uniform. Earth, on the other hand, may form a definite boundary of a channel when new, but after a few years of operation the character of the boundary has entirely changed. Grass, weeds, and fibrous roots may form the material for nearly vertical sides, while the bottom may silt up or scour deeper, be smooth, or deeply pocketed. A distinct trapezoidal form changes to a segment of an ellipse, silt depositing in the lower corners, while the middle of the bed remains about the same or becomes strewn with rocks or gravel.

The values of n given in the following list cover the standard conditions, while a study of the descriptions of the channels under the earth-channel headings will disclose the influence that changes the value of n from one of these standards.

I. $n=0.016$ for excellent conditions of earth channels. The velocity to be so low that a slick deposit of silt may accumulate, or the natural material be such as to become smooth when wet. The influence of vegetation at the edges to be a minimum. The water to be free from moss and other aquatic growth. The alignment to be free from bends and sharp curves.

II. $n=0.020$ for well-constructed canals in firm earth or fine, packed gravel where velocities are such that silt may fill the interstices in the gravel. The banks to be clean-cut and free from disturbing vegetation. The alignment to be reasonably straight.

III. $n=0.0225$, although carried to one more significant figure, is given for the reason that it has long been used for this type and the tests do not disclose any reason for changing. This value for the average well-constructed canal in material which will eventually have a medium-smooth bottom, with graded gravel, grass on the edges and average alignment or silt at both sides of the bed and scattered stones in the middle, or a smooth bottom with an average amount of grass and roots forming the sides. Hardpan in good condition, clay and lava-ash soil takes about this value.

IV. $n=0.025$ for canals where the retarding influence of moss, growths of dense grass near the edges, or scattered cobbles begins to show. The value of n in earth channels where the maintenance is neglected commences at this value and rapidly goes up. This is a good value to use in the design of small head ditches or a small ditch to serve but one or two farms.

V. $n=0.030$ for canals subject to heavy growths of moss or other aquatic plants. Banks irregular or overhanging with dense rootlets. Bottom covered with large fragments of rock, or bed badly pitted by erosion. Values of n between 0.025 and 0.030 also cover the condition where the velocity is so high that cobbles are kept clean and unpacked in the center of the canal, but silt deposits near the sides. For values above 0.030 the channel is much choked with vegetation, very irregular, crooked, overhung with dragging trees and grasses, or there is some other condition that should not be allowed to exist in a well-kept system.

VALUES OF n FOR COBBLE-BOTTOM CANALS.

The typical clean-washed cobblestone ditch is very common near the mouths of canyons. Where the cobbles are graded in size and well packed the value of n is about 0.027, but the value rapidly increases as the larger rocks predominate and the lack of graded sizes prevents packing.

ESTIMATION CHARTS.

As an aid to the designer of irrigation channels the writer has prepared two sets of curve charts.

The first set shows values of width and depth of channel as related to area and hydraulic radius. These elements for rectangular channels are shown in figure 4 and for trapezoidal channels having side slopes of 1½ to 1 in figure 5. These cover the two shapes most commonly used, while the engineer working in materials that require other slopes may build up his own charts on the principle used in plotting figures 4 and 5.

The second set shows related values of velocity, slope, the friction factor n, and the hydraulic radius. This set is divided into three general classes. First. For construction in concrete, wood, or steel for ordinary slopes (fig. 6). Second. For the same materials of construction on very steep slopes (fig. 7). The latter chart is for use in the design of chute drops and covers slopes from 0.005 where figure

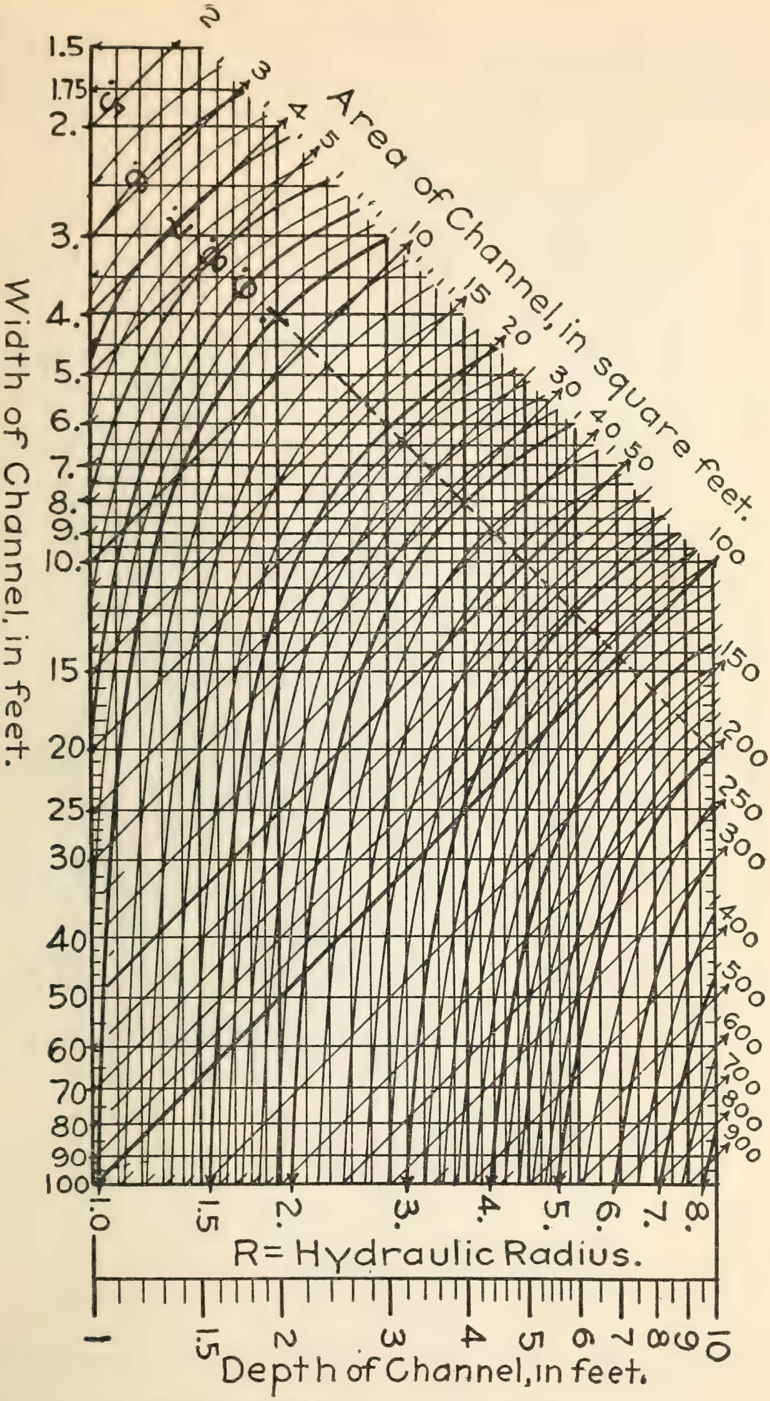

FIG. 4.—Areas, in square feet; hydraulic radii, in feet and hydraulic economic dimensions (broken line) for rectangular channels.

6 stops, up to 0.3, or 30 feet per hundred. Third. For very rough materials, for earth channels and for cobble-bottom ditches (fig. 8). The values of *n* range from 0.015 to 0.030 while the slopes cover all ranges likely to be encountered. On this chart the values of *n* cover such a wide range that the guide lines through any particular zone have not quite the same slant, but the results obtainable from any of these charts are more accurate than the agreement between preliminary figures and results of tests made after construction.

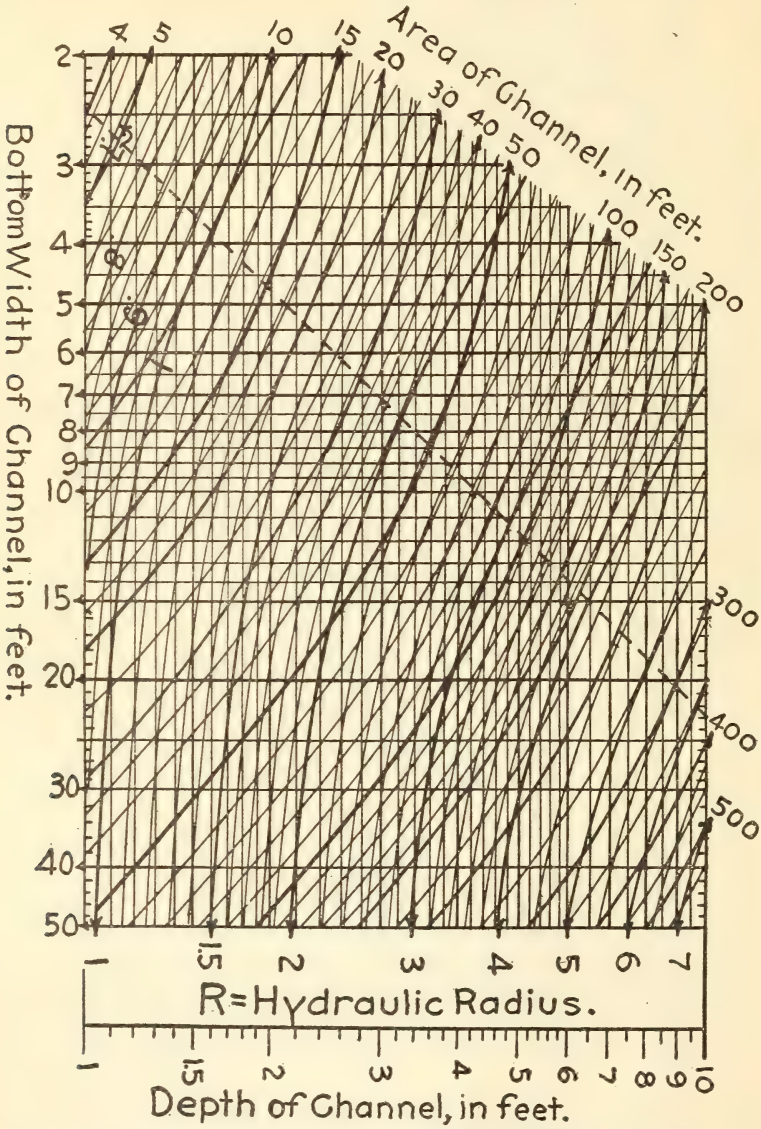

FIG. 5.—Areas, in square feet; hydraulic radii, in feet and hydraulic economic dimensions (broken line) for channels having side slopes of 1½ to 1.

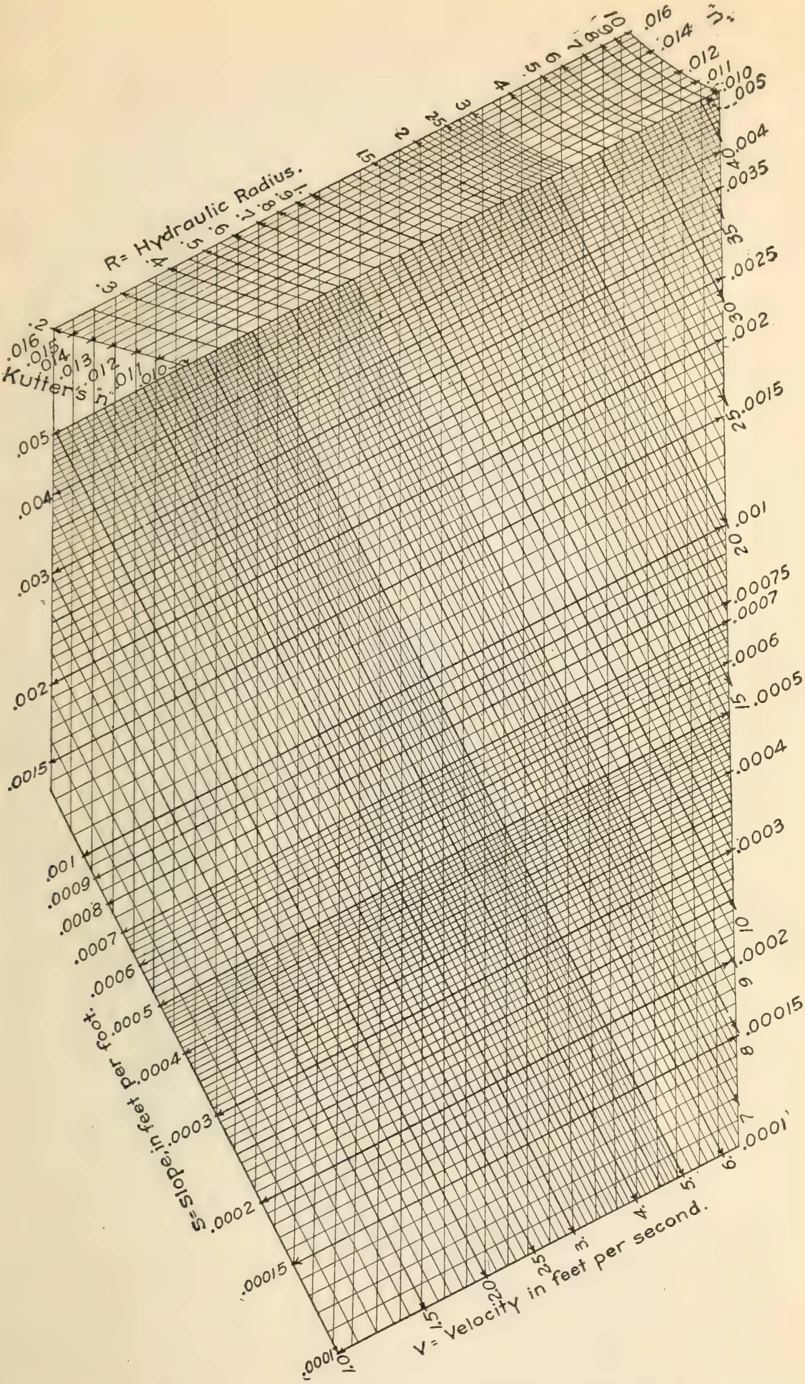

FIG. 6.—Chart for use in designing ordinary concrete, wood, or steel channels on moderate slopes. From the intersection of R and *n* follow guide lines to intersection of S and V.

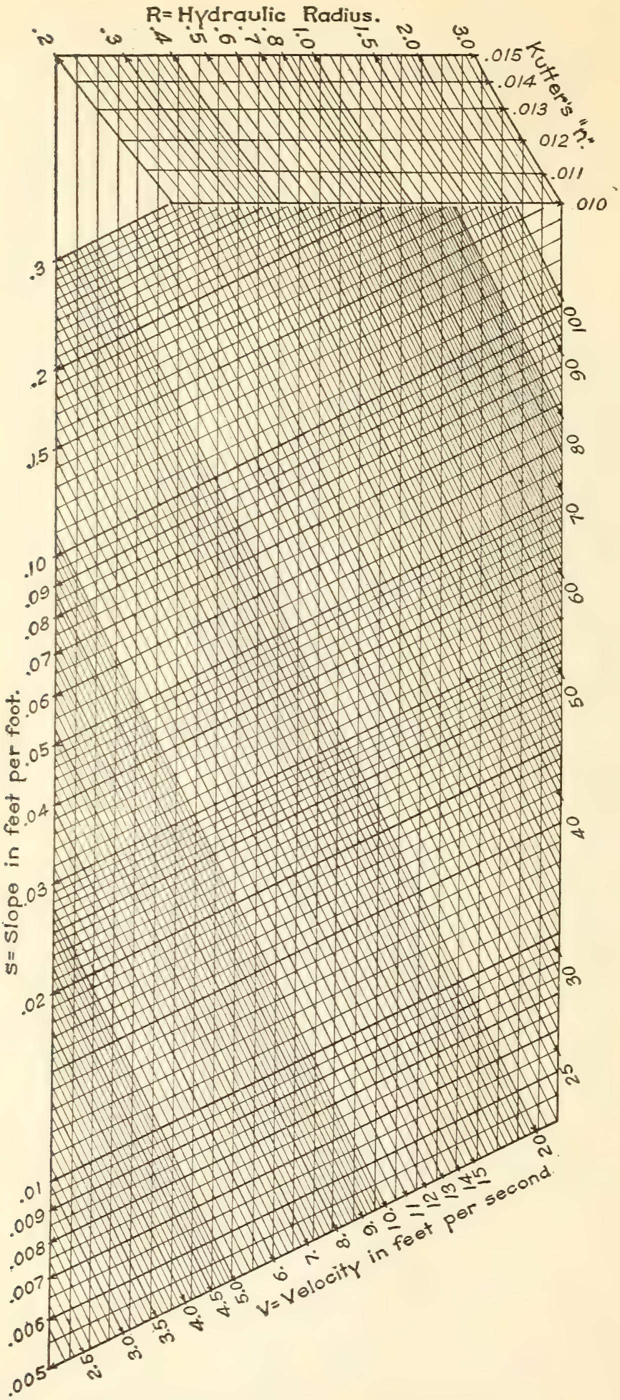

FIG. 7.—Chart for use in designing concrete, wood, or steel channels on very steep slopes; particularly for chute drops. From the intersection of R and *n* follow guide lines to intersection of S and V.

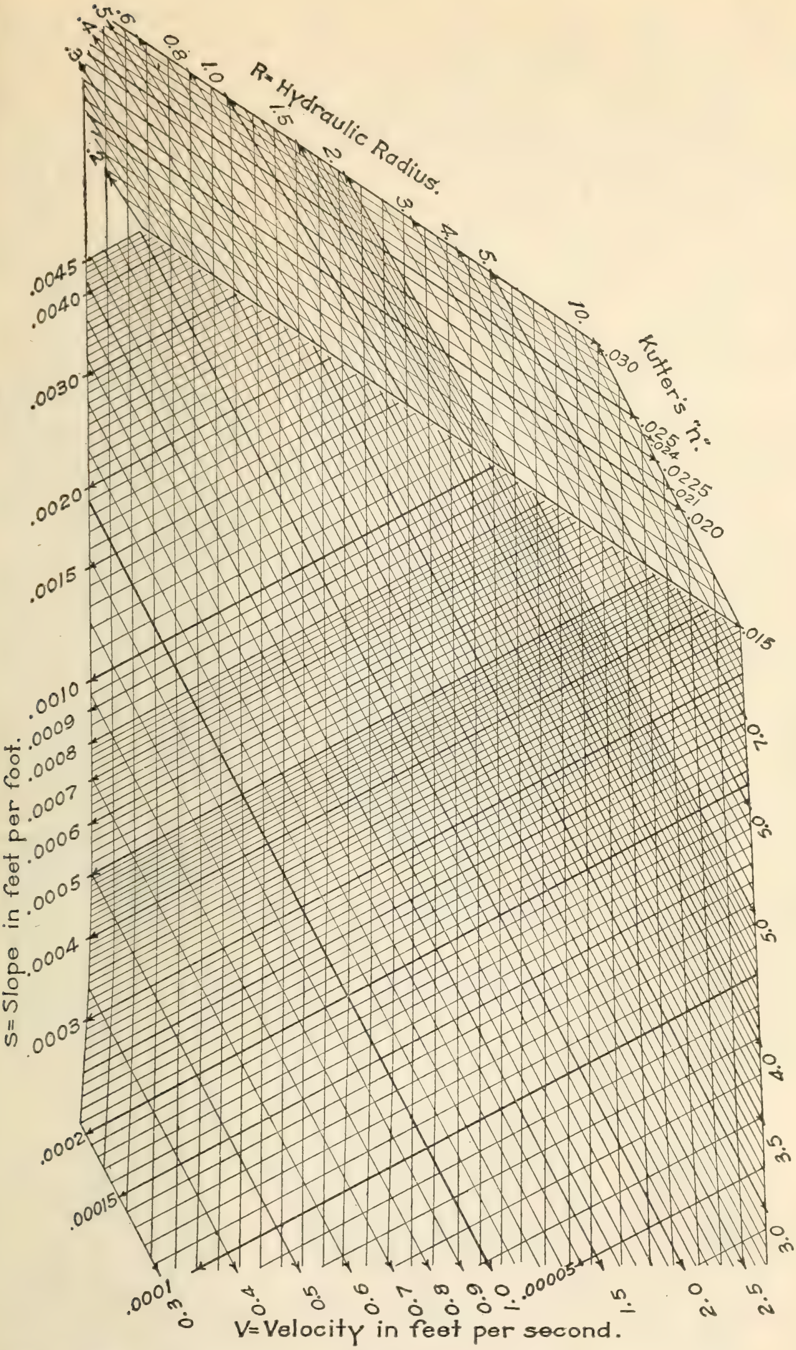

FIG. 8.—Chart for use in designing rough masonry, rough-coated concrete, or earth channels. From intersection of R and *n* follow guide lines to intersection of S and V.

Use of charts. Assume that it is desired to construct in well-made concrete a channel that will carry 1,000 second-feet of water at a mean velocity of 10 feet per second. Allow as a safety factor an overload of 5 per cent, making the designed capacity 1,050 second-feet. Therefore the area of such a channel must be 105 square feet. To test the possibilities of a rectangular cross section refer to figure 4. Any point on the ''area'' line representing a value of 105 will show values of depth, width, and hydraulic radius corresponding to this area, but the most economic channel—that is, the one having the least area for the greatest hydraulic radius—is at the point of intersection with the broken line. Therefore it is desirable to approach as nearly as possible to a channel 14.5 feet wide by 7.2 feet deep. A further study of the chart shows the hydraulic radius of such a channel to have a value of about 3.6 feet. Assume that the character of the lining, curvature, and so on should give a value of *n* of 0.012. Turning to figure 6, follow a line parallel to the guide lines from the point of intersection of *n* equals 0.012 and R equals 3.6 feet. This line intersects the velocity line equal to 10 feet per second on a slope line equal to 0.00122 feet per foot. But suppose the topography of the land to be such that a slope of 0.00122 is not obtainable or is not desirable. Suppose the best location for a canal is on a slope of 0.0015 feet per foot. The intersection of 10 feet per second velocity line with 0.0015 feet per foot slope line is down the guide lines from the intersection of *n* line of 0.012 and hydraulic radius line of 3.1. With this value for hydraulic radius go back to figure 4, and the intersection of area line 105 square feet and hydraulic radius line 3.1 shows the water section of the necessary channel to be 25.5 feet wide and 4.1 feet deep, while the same intersection on figure 5 gives a trapezoidal channel 19 feet wide on the bottom and 4.2 feet deep.

Figures 6, 7, and 8 may be used for the general solution of problems involving Kutter's formula. Given any three of the variables—slope, radius, *n* and velocity, and the fourth may be determined as accurately as is warranted.

VARIATIONS OF *n* IN THE SAME CHANNEL.

It is well known that the same channel does not necessarily have the same value of *n* throughout the season. Vegetable growths, especially moss, may so change the value of *n* from early spring to the middle of summer that the channel may carry but 75 per cent of its rated capacity for the same depth of water in the channel. The writer made a series of current-meter measurements on a prominent canal near North Yakima, Wash., during the month of July, 1914. The canal was rated and had carried more than 70 second-feet when clean in the spring, but in July it carried but 62 second-feet, although running bank full. The velocity was retarded by moss accumulations. As the total capacity of the canal is needed throughout the season, it would have been better to design this concrete channel for a value of *n* about 0.017 for moss and sharp bends than to use a value of 0.012 as was done. A high velocity would have resulted during the months when the canal was cleaned, but this would not have injured the concrete and might have delayed the deposit of moss, although this is doubtful.

Some writers have contended that the value of *n* decreases as velocity or hydraulic radius increases, the condition of channel remaining the same. Wherever the experiments tabulated in Table I contained more than one test in the same reach of channel at the same time of year (approximately the same date) the writer has plotted the results shown in figure 9 and connected comparable points by broken lines. Values of *n* as abscissæ and V as ordinates

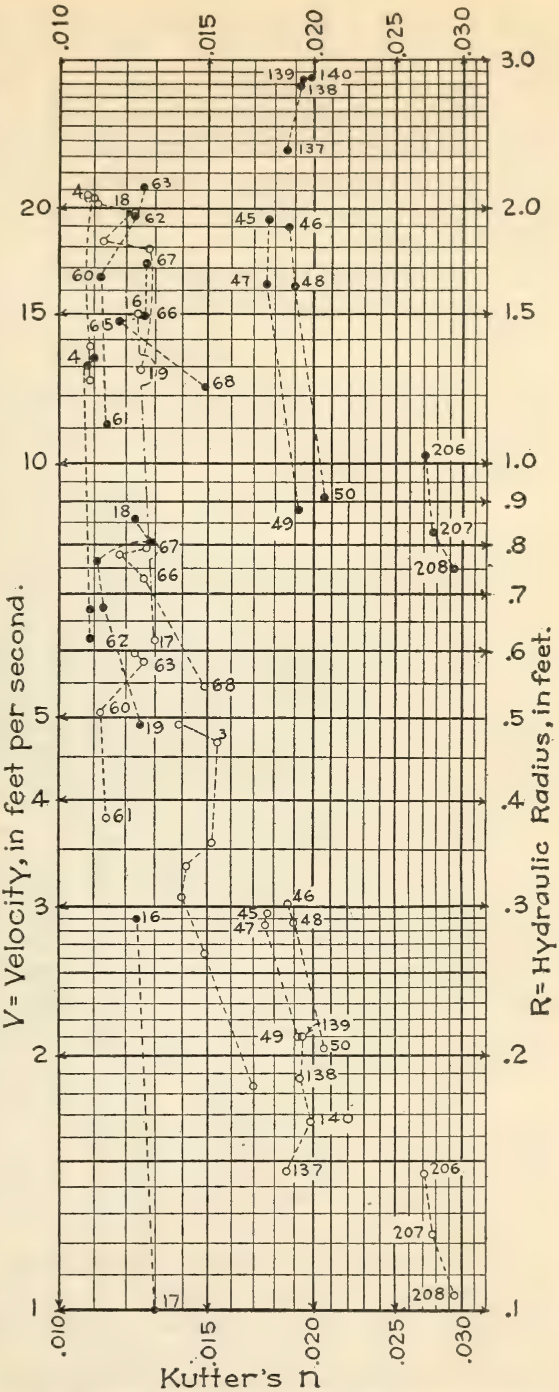

FIG. 9.—Diagram showing variation of *n* with varying velocities (open circles) and with varying hydraulic radii (dots) as the discharge is varied in the same reach of the same channels at the same time of year.

are designated by open circles and numbered to correspond with the numbers in column 1, Table I. For the same tests the values of R as ordinates are also plotted as dots. As a general statement there is a distinct tendency for *n* to decrease as the velocity and hydraulic radius increase, although in some cases the opposite effect is noted. The slope of the decrease in *n* is rather uniform, but the writer did not feel that the evidence was sufficient to attempt to deduce a formula to cover it.

A chart showing this change for values of *n* usually assigned to earth channels has previously been published.[1]

CONCLUSIONS.

A careful study of the data on the previous pages and of the experiments carried out by others appears to warrant the following general conclusions:

(1) That Kutter's formula is applicable to the design of any open channel.

(2) That the recommendations of the earlier writers concerning the values of *n* to be chosen were in the main correct. Any weakness was due to the fact that there was not sufficient distinction made between the various categories and that materials of construction are now used which were not covered by the tests from which early deductions were made. The influence of curves was not as a rule included. Concrete lining covered but one value of *n*, whereas in practice there are many shades of roughness, all applicable under the general head of concrete.

(3) That the factor *n* must include all the influences which tend to retard velocity. The principal of these influences are undoubtedly (*a*) rubbing friction between the water and the containing channels, and (*b*) vegetable growth extending into the main body of the water. The lack of carrying capacity in many channels is probably due to the fact that the first influence was the only one considered. Of secondary importance, but nevertheless deserving of careful consideration in about the order named, are the following: (*c*) Angles and sharp curves in the alignment. (*d*) Influences which tend to disturb parallel filaments of current. The concrete lining in a rough rock cut may be quite smooth to the feel of the hand and yet be so undulating as to cause heavy cross currents which retard velocity. All projections and irregularities in the bank of a canal disturb the filaments of current in addition to having a large area exposed to rubbing friction. (*e*) Sand and gravel cause heavy loss in velocity when allowed to enter and accumulate in shifting patches on a lined canal bed. Fine sand drifts downstream in deep, irregular pockets and

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[1] C. T. Johnson and R. D. Goodrich. A Formula and Diagram for Determining the Velocity of Flow in Ditches and Canals. Engin. Rec., 64 (1911), No. 19, p. 542.

may entirely change the character of the bottom of a smoothly lined canal. On the other hand, a water laden with fine silt flows far more freely after the silt has deposited in a slick coat over minor irregularities than in a new, though clean, canal. A canal carrying such a water may be designed for a far higher velocity through the same kind of soil than would be the case if the water were clear. It is necessary only to run but low heads in the new canal until a thick waxy deposit has been placed on the canal bed, after which the velocity may be nearly doubled over that which would have scoured the material in which the canal was originally excavated. (*f*) The prevailing wind direction may be given some consideration. A study of vertical velocity curves shows a marked change in form with change in wind condition. A downstream wind aids the flow of surface water to the extent that it has the maximum velocity in the vertical, while an upstream wind so shapes the velocity curve that the surface velocity is as slow as that near the bottom.

(4) That there is a tendency toward a lower value of n as the velocity and hydraulic radius increase. Any experiments that are intended to bring out conclusively the extent of the variation and whether it is due to the change in velocity or the change in hydraulic radius must be conducted in very long, straight channels, in wood, or concrete, or steel, where the character of the wetted perimeter will remain unchanged as the water becomes deeper and deeper in the channel. Proper corrections must be applied for any slight changes in the mean velocity at the two ends of the reach tested. The reach must be far removed from all influence of curves and structures.

(5) That a value of n must be chosen that will apply to the canal in question at the critical period of the season. For instance, most canals are cleaned once a year. A growth of moss may become very heavy by July or August, but the water supply or demand will probably be much less than during the early days of June. If the canal is designed to carry its peak load on the basis of its being in good condition, there will still be sufficient carrying capacity for the smaller discharge when moss has appeared.

(6) That in the design of earth channels having a trapezoidal form when constructed, the value of R should be computed on the basis that the canal takes an elliptical form within a short time and thereafter maintains this shape unless altered artificially.

ACKNOWLEDGMENTS.

The writer and his associates desire to acknowledge indebtedness to the various engineers and managers of irrigation and power systems who permitted the use of canals under their charge for the tests and to the engineers of the United States Reclamation Service who allowed access to much original data on tests made by their engineers.

APPENDIX.

The following pages are devoted to abstracts of descriptions of canals on which tests have been made in recent years by other agencies than irrigation investigations of the Office of Experiment Stations. The first number refers to the corresponding number in Table I, page 19. Next follows the symbol referring to the experimenter, as listed on page 16. Tests marked * are described in detail in Engin. News, 57 (1907), No. 23; those marked ** are described in United States Geological Survey Water-Supply and Irrigation Paper 43 (1901); those marked *** are described in United States Reclamation Service Reclamation Record, 4 (1913), No. 7; those marked + are described in Colorado Station Bulletin 194 (1914); those marked ++ are described in University of Colorado Studies, 7 (1910), No. 4.

CONCRETE LININGS.

No. 2, R. S., 14***, main canal, Boise project, United States Reclamation Service. Rather rough, in places disintegrated by frost. Fairly clean but still some rock in bottom. Other tests in same section gives values of n from 0.0129 to 0.0148. Coefficient n=0.0130.

No. 3, R. S., 8***, main canal, Boise project, United States Reclamation Service. Rough troweled. Small deposit rocks and gravel in bottom. Coefficient n=0.0154.

No. 4, R. S., 36***, Sulphur Creek wasteway, Sunnyside unit, United States Reclamation Service. This covers one of four tests in same section, with discharges from 45 to 247 second-feet. Corresponding values of n are the same, within 0.0002 for all discharges. Wood forms used; no retouching of surface. Circular section, radius 4 feet. Coefficient n=0.0108.

No. 5, R. S., 33***, Sulphur Creek wasteway. Similar to No. 4 above, but on 2° curve. One of three tests with discharges from 52.5 to 247 second-feet. Corresponding values of n same within 0.0004. Coefficient n=0.0140.

No. 6, JBL–6*, main supply conduit for Los Angeles, Cal. Covered conduit. In use four years, one curve in section tested. Where wetted, section was very smooth. Apparently of 1 to 3 cement-mortar plaster on concrete. No deposit or growth. Coefficient n=0.0108.

No. 7, JBL–5*. Description and reach tested same as No. 6 above. Coefficient n=0.0111.

No. 8, JBL–2*, tunnel 23, San Gabriel plant of Pacific Light & Power Co., California. Covered conduit. In use eight years. No growth. Deposit conditions indeterminate. Slight curves near each portal. Slope determined by correcting office notes of floor grade by depths of water. Coefficient n=0.0113.

No. 9, VMC+, Dry Creek flume, Handy Canal, Loveland, Colo. In good condition. Lined in 1906 with cement mortar, trowel finish. Coefficient n=0.0115.

No. 10, JBL–1*, tunnel 15, San Gabriel plant, Pacific Light & Power Co., California. A tunnel similar to No. 8 above. Slight curve at upper portal. Sharp angle 20 feet below lower portal. Deposit conditions indeterminate. Coefficient n=0.0128.

No. 15, R. S., 20***, Ridenbaugh Canal, Idaho. Description similar to Nos. 12–13 in text. One of three tests with discharges 50, 103, and 230 second-feet. Corresponding values of n are 0.0132, 0.0130, and 0.0122.

No. 16, R. S., Lizard chute, Boise project, United States Reclamation Service. Straight, very smooth and uniform. Sides battered 1 in 12. Meter measurement in canal below chute. The chute is 900 feet long, in three slopes. Coefficient n=0.0124.

No. 17, R. S. Same section as No. 16 above with different discharge. Coefficient n=0.0130.

No. 18, VMC+, Long Pond chute near Fort Collins, Colo. A reinforced concrete chute carrying water on steep grade at velocities from 12 to 20 feet per second. Constructed in 1910. Meter measurements made in 1912 near inlet in lower velocities. Elements determined by measurements down from bench marks to top and bottom of pulsations. Mean of these two measurements accepted. These tests two of five, made with discharges ranging from 35.79 to 122.94 second-feet. The values of n range inconsistently from 0.0125 down to 0.0111 for discharge of about 104 second-feet and then back to 0.0123 for the greatest discharge.

No. 19, VMC+. Same channel and reach as No. 18 above. Coefficient n=0.0125.

No. 20, R. S., 5***, Umatilla project, United States Reclamation Service. Smooth, regular, section on a slight curve. Coefficient n=0.013.

No. 21, R. S., 1***, Umatilla project, United States Reclamation Service. Circular, 4.9 feet radius. As left by wood forms. On tangent. Coefficient n=0.0132.

No. 22, R. S., 4***. Same conduit but on curve of 100 feet radius. Coefficient n=0.0142.

No. 23, R. S., 3***. Same conduit but on a curve of 50 feet radius. Coefficient n=0.0189.[1]

No. 24, R. S., Arena chute, Boise project, United States Reclamation Service. Straight, very smooth and uniform. Sides battered 1 in 6. Meter measurement in canal below chute. Coefficient n=0.0139.

No. 32, VMC+, South Canal, Uncompahgre project, United States Reclamation Service, Colorado. This and the following two tests made on short sections between curves. Gives experience on steep grades, in lining as left by forms with boards laid longitudinally. Canal carrying less than one-tenth rated capacity. Coefficient n=0.0155.

No. 33, VMC+. Same canal and description as No. 32 above. Coefficient n=0.0158.

No. 34, VMC+. Same canal and description as No. 32 above. Coefficient n=0.0171.

No. 36, JBL–8*, Santa Ana Canal, near Yorba, Cal. Concrete tamped behind board forms. No plaster coat. Section wide and shallow. Several inches of sand in bottom. Moss and grass in patches on sides. Coefficient n=0.0157.

No. 39, JBL–7*, Colton Canal, near Colton, Cal. Lining of unplastered concrete. No sand or gravel. Sides and bottom covered with thin coat of moss. Coefficient n=0.0167.

No. 52, JBL–4*, Upper Canal, Riverside Water Co., California. Coat of 1 to 3 cement plaster roughly applied to concrete. Canal partially cleaned of a stringy grass a few days before test. Isolated bunches of grass left in bottom. Two curves included in reach. Coefficient n=0.0218.

No. 56, JBL–3*, Riverside Canal, California. From 1.5 to 2.5 feet of sand in bottom of canal lined with 1 to 3 plaster coat on concrete. Top sand shifting downstream (see No. 55). Sides covered with feathery grass sometimes 1 foot long. Containing boundary 75 per cent shifting sand and 25 per cent water grass. Two curves in reach. Canal equivalent of earthen channel with loose sediment bottom. Coefficient n=0.0284.

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[1] Details of above three tests in Engin. News, 69 (1913), No. 18, p. 904.

WOODEN FLUMES.

Nos. 60, 61, 62, 63, VMC+, Orchard Mesa Power Canal near Palisade, Colo. Lumber, planed, with tongued and grooved joints and with vertical pieces of 2 by 4 inch lumber in nearly all sections to check velocity in low discharge to keep flume wet. Straight reaches from less than 100 up to 600 feet long, joined at angular turns. Flume built in 1909–10. Has sagged below grade 0.3 foot in places. Of 22 reaches tested 17 show higher values of n for highest than for lowest discharge. The average value of n was 0.0122 for 75 tests on 22 reaches.

No. 69, R. S., Fargo drop, Boise project, United States Reclamation Service. Smooth planed plank coated with tar. Coefficient $n=0.0122$.

No. 76, SF–23**, Bear River Canal flume over Malad River, Utah. Test made on 125-foot wooden portion of flume. Reach above was 200 feet of iron and steel flume lined with riveted plates. Lower portion of planed wood. No gravel or sediment. Coefficient $n=0.0142$.

No. 81, VMC+, Oxford Canal, Fowler, Colo. Structure 23 years old. In good condition as to grade and alignment. Sides of 2 by 12 inch lumber battened with $\frac{1}{4}$ by 3 inch strips. Floor laid at right angles to axis of flume. Though apparently smooth, has a high frictional factor. Tendency to cause deposit of silt lessens leakage. Coefficient $n=0.0150$.

No. 92, SF–45**, small flume near Corinne, Utah. Planed lumber calked with oakum which projected in places. Coefficient $n=0.0184$.

No. 95, SF–8**, Bear River Canal, Utah. At mouth of Bear River Canyon. Originally of planed lumber, the floor was almost entirely covered with sediment and rock fragments. Coefficient $n=0.0201$.

No. 97, SF–10**, Bear River Canal, Utah. Located 2 miles above No. 95. Floor covered with sediment, gravel, and small cobbles. Coefficient $n=0.0217$.

METAL FLUMES WITH SMOOTH INTERIOR.

No. 98, VMC+, Minnesota Canal near Paonia, Colo. Grade not uniform. No transverse bracing, so flume sagged and took parabolic rather than semicircular form. This reach 200 feet long. On similar reach 70 feet long found n to be 0.0111, but this reach is too short for good test. Coefficient $n=0.0099$.

No. 99, VMC+, Garland Canal, Trinchera Irrigation District, Colorado. A new No. 168 flume in perfect alignment and excellently constructed. Coefficient $n=0.0101$.

No. 100, R. S., Boise project, United States Reclamation Service. This flume has a lap joint with smooth interior. It is 30 inches in diameter; was new and clean. Coefficient $n=0.0106$.

No. 101, R. S., Boise project, United States Reclamation Service. This flume has outside and inside stay rods. Interior smooth and clean. Semicircumference 80 inches long. Coefficient $n=0.0117$.

No. 102, R. S., Mora Canal, Idaho. Smooth, clean interior. Semicircumference 108 inches long. Coefficient $n=0.0112$.

No. 103, R. S., Yarnell lateral, Idaho. Smooth, clean interior. Semicircumference 72 inches long. Coefficient $n=0.0122$.

No. 104, VMC+. Another reach on flume No. 99 above. Same conditions. Coefficient $n=0.0126$.

METAL FLUMES WITH PROJECTING INTERIOR BANDS.

No. 105, R. S., Partridge lateral, Idaho. Semicircumference 48 inches long. Flume clean. Coefficient $n=0.0127$.

No. 106, R. S., Golden Gulch flume, Idaho. Semicircumference 108 inches long. Flume clean. Coefficient $n=0.0129$.

No. 107, R. S., Ten-Mile feeder, Idaho. Semicircumference 144 inches long. Flume clean. Coefficient n=0.013.

No. 108, R. S., South Ridge Canal, section 1, Idaho. Semicircumference 60 inches long. Flume clean. Coefficient n=0.0139.

No. 109, VMC+, King lateral extension, Uncompahgre project, United States Reclamation Service, Colorado. Excellently constructed as to alignment and grade. No. 108 flume. Coefficient n=0.0179.

No. 110, VMC+. Same system as No. 109 above. Same class of construction. No. 120 flume. Coefficient n=0.0177.

No. 111, VMC+. Same system as Nos. 109 and 110 above. Same class of construction. No. 96 flume. Coefficient n=0.0166.

METAL FLUMES OF CORRUGATED IRON.

No. 112, VMC+, Stewart Canal near Paonia, Colo. A No. 132 flume with numerous curves. Test in table covers whole flume. Value of n for portions of flume range from 0.0196 on a reach, most of which was on a curve of 300 feet radius to 0.0224 on a tangent. A similar test on a reach of No. 144 flume 278 feet long, with two curves, gave a value of 0.0230 for n. Coefficient n=0.0222.

MASONRY-LINED SECTIONS.

No. 114, R. S., Cottonwood flume, Idaho. Rubblestone fairly well laid. Some coarse sand in bed being carried as silt. Coefficient n=0.0163.

EARTH CHANNELS.

No. 118, W–14++, Interstate Canal, Nebraska. In same soil and with same general description as No. 120. This canal designed with frictional factor of 0.025, but on account of high velocity maximum discharge allowed is 830 second-feet instead of the 1,421 second-feet for which designed. Coefficient n=0.012.

No. 121, SF–21**, Bear River Canal, Utah. Canal six years old. Section changed from trapezoidal with 1 to 1 slopes to present form. Bottom covered with sediment, but free from gravel and growth. Coefficient n=0.0134.

No. 122, SF–12**, Bear River City Canal, Utah. Age and condition similar to No. 121 above of which this canal is a branch. Coefficient n=0.0135.

No. 123, SF–15**, Corinne branch, Bear River Canal, Utah. Reach free from growth. Originally trapezoidal in clayey loam now segment of ellipse lined with smooth silt. Six years old. Coefficient n=0.0155.

No. 124, SF–22**. Same canal as No. 123 above. Same conditions but carrying a small part of rated capacity. Coefficient n=0.0164.

No. 125, VMC+, Fort Lyons Canal, Colorado. Carrying but 7 per cent of capacity, merely covering bottom. Slight curves at ends of reach. Bottom fine silt, merging into sand. In places boggy. Exceptionally smooth, regular, and free from impediments. Coefficient n=0.0165.

No. 128, W–1b++, Empire Intake Canal, Colorado. Straight, grade uniform, channel in firm sand, and gravel having no pebbles larger than one-half inch diameter. No vegetation. Two years old. Coefficient n=0.0170.

No. 129, W–1++. Same reach as No. 128 above with different discharge. Coefficient n=0.0194.

No. 131, VMC+, Jarbeau Power Canal near Rifle, Colo. New. First third of reach in clayey loam with few water-worn stones projecting. Rest of reach in clayey loam in which moss was starting. Coefficient n=0.0176.

No. 136, SF–3**, Logan, Hyde Park and Smithfield Canal near Logan, Utah. In operation 15 years. Bottom and sides smooth earth and gravel up to 1 inch in diameter with some pebbles 2 inches. Slight growth of grass on one side. In opinion of writer value of n is lower than might be expected. Coefficient n=0.0184.

No. 143, SF–13**, small lateral from Corinne Branch Bear River Canal, Utah. In good condition. Excavated in clayey loam. Now well lined with silt. Numerous footprints of stock in bed. Coefficient n=0.0194.

No. 144, SF–16**, Millville and Providence Canal. Constructed 33 years before test in compact clay dotted with small rock fragments one-half inch diameter. One side perfectly smooth, other side has willow roots. Few small cobbles in bed. Otherwise good condition. Coefficient n=0.0195.

No. 146, SF–17**, Logan and Hyde Park Canal in Logan, Utah. Bed of clay covered with thin layer of fine sand. About one-sixth of perimeter covered with low creeping water plant. (Value of n is lower than might be expected in opinion of writer.) Coefficient n=0.0197.

No. 147, VMC+, Mesa lateral a, Grand Valley Canal, Colorado. Carrying nearly full capacity. Bed lined with fine sediment. Sides rather uneven surface of clay loam. Short grass on bank was submerged one-half foot. Coefficient n=0.0200.

No. 148, SF–20**, Solveson & Co. Canal, Utah. Channel of small pebbles embedded in sand. Coefficient n=0.0201.

No. 150, SF–48**, lateral of Logan City Canal, Utah. Channel of pebbles size of a pea, embedded in finer material. No aquatic growth. Coefficient n=0.0204.

No. 152, W–3++, Rist and Goss Ditch, Colorado. Built in heavy loam. Sides and bottom well coated. No weeds or aquatic growth. Coefficient n=0.0204.

No. 153, VMC+, Willcox Canal, Rifle, Colo. Bed of fine silt, sand, and pebbles, with thin scattering of 6-inch cobbles. Discharge tested less than one-twentieth of rated capacity. Coefficient n=0.0205.

No. 154, W–4++, Old Barnes Ditch, Colorado. In good condition. Constructed in firm earth. Channel well coated with sediment. No stones or pebbles, but some long grass overhangs banks. Coefficient n=0.0206.

No. 156, SF–6**, Logan and Richmond Canal, Utah. Bed smooth and free from vegetation. Some indentations near top of channel. Coefficient n=0.0211.

No. 159, SF–4**, Logan, Hyde Park and Smithfield Canal, Utah. Channel composed of well-packed gravel, mostly of stones from 1 to 3 inches in diameter in equal proportion. (This value appears low to the writer.) Coefficient n=0.0213.

No. 163, SF–11**, Point Lookout Canal, Utah. When tested carrying about one-seventh of capacity. Channel smooth clayey loam lined with sediment. No vegetation in the reach, but some both above and below. Coefficient n=0.0218.

No. 165, VMC+, Bessemer Canal, Pueblo, Colo. Bed of smooth waterworn adobe. Coefficient n=0.0219.

No. 166, VMC+. Same canal as No. 165 above. Channel the same except for the presence of cottonwood tree rootlets at the sides. Coefficient n=0.0281.

No. 168, W–2++, Louden Ditch, Colorado. Bed has clean, sandy bottom without growth of any kind. Would be considered in fair condition. Coefficient n=0.0220.

No. 169, VMC+, Mesa lateral, Grand Valley Canal, Colorado. Bed smoothly lined with fine sediment. Sides of uneven loam. Short grass on bank submerged one-half foot. Coefficient n=0.0220.

No. 170, VMC+, Rio Grande, lateral 1–c, Del Norte, Colo. Description about the same as for No. 171, except that the gravel is finer. Coefficient n=0.0221.

No. 171, VMC+, Rio Grande, lateral 1, Del Norte, Colo. Bed varies from fine gravel to smooth round rocks about 6 inches in diameter. Coefficient n=0.0390.

No. 176, SF–19**, Lewiston Canal, Utah. At time of test carrying one-fourth rated capacity. Bed of smooth clay. About one-fifth of perimeter covered with frog moss. Coefficient n=0.0224.

No. 177, W-5++, Geo. Rist Ditch, Colorado. Originally excavated in material ranging from earth to coarse gravel with occasional cobbles up to 6-inch size. Bed lined with sediment. Banks uneven and overhung with sod. Coefficient n=0.0224.

No. 181, SF-31**, Providence Upper Canal, Utah. Coefficient n=0.0229.

No. 182, SF-14**, lateral of Bear River Canal, Utah. Originally excavated in clayey loam. Now bed covered with sediment. Patches of horsetail moss. Edges uneven. Coefficient n=0.0230.

No. 183, SF-39**, lateral 2, Bear River Canal, Utah. Conditions similar to No. 182 above except there was no moss and some bunches of grass along the edges retarded velocity. Coefficient n=0.0230.

No. 185, SF-9**, Walker Tract Canal, Utah. Channel in clayey loam free from vegetation. Low grade due to check dams in ditch, Coefficient n=0.0232.

No. 187, SF-1**, Providence Canal, Utah. In gravel size of peas with scattered pieces size of walnuts. No vegetation. Coefficient n=0.0238.

No. 188, SF-5**, College and City Canal, Utah. Bed of gravel from ½ to 2 inch size embedded in finer material. Edges somewhat irregular with willow roots, otherwise no vegetation. Coefficient n=0.0238.

No. 189, SF-27**, Logan, Hyde Park and Thatcher Canal, Utah. Sides smooth with sediment. Bottom of earth, gravel, and pebbles up to 2½ inches diameter. Coarser material covered one-fourth of perimeter. Coefficient n=0.0246.

No. 191, SF-18**, College and City Canal, Utah. No vegetation, but sides uneven. Bed covered with fragments of flat rock from ½ to 2 inches in greatest dimension. Coefficient n=0.0247.

No. 196, SF-63**, Hyrum Canal, Utah. Sides of earth. One-half of perimeter across bottom covered with rock fragments up to 1 inch across. Weeds and alfalfa grew up to water's edge. Coefficient n=0.0260.

No. 201, VMC+, Rocky Ford Canal, Colorado. Bed of fine loose sand. Sides of clay with fine grass roots projecting. Some grass overhangs into water. Canal somewhat crooked and banks irregular. Coefficient n=0.0266.

No. 203, W-7++, Loveland and Greeley Canal, Colorado. Overhanging sod banks with grass in water. Earth channel with many cobbles up to 8 inches diameter. Reach tested on a curve. Coefficient n=0.0267.

No. 211, VMC+, Bessemer Ditch, Colorado. Bed of fine silt merging into clays with liberal sprinkling of loose stones up to 3 inches diameter. Coefficient n=0.0280.

No. 214, VMC+, Rio Grande lateral No. 1, Colorado. Bed composed of graded material from fine gravel to waterworn rocks 6 inches or more in diameter. Discharge was measured 1 mile above reach tested, and 2 per cent arbitrarily deducted for seepage loss. Three tests made on the same reach with discharge of 380 second-feet, 33.34 second-feet, and 27.16 second-feet, gave values of n as 0.0284, 0.0386, and 0.0370, respectively. This gives a lower value of n for the greater discharge.

No. 217, SF-42**, a central farm lateral of Bear River Canal, Utah. Bed of clay, with uneven cross section. Bunches of grass scattered along edges. Coefficient n=0.0293.

No. 218, SF-37**, a central farm lateral of Bear River Canal, Utah. A similar canal and section as that in No. 217 above. Coefficient n=0.0295.

No. 225, SF-64**, Hyrum Canal, Utah. Sides overgrown with alfalfa and weeds. Bed of coarse gravel up to walnut size. Coefficient n=0.0319.

No. 226, W-12++, Beasley Ditch, Boulder, Colo. Excavated in gravel and fine sand with a good many small cobbles. Banks held in place by logs laid parallel to stream. Coefficient n=0.0320.

No. 227, VMC+, Bessemer Canal, Colorado. Bed of fine silt, merging into clays with liberal sprinkling of loose stones up to 3 inches diameter. Coefficient n=0.0321.

No. 229, SF-55**, Smithfield Canal lateral, Utah. Cobbles partially covered with silt. Edges made irregular by cattle. Coefficient n=0.0329.

No. 232, SF–26**, Logan and Benson-Ward Canal, Utah. Bed of medium-sized gravel. Flow much impeded by horsetail moss which occupied about one-fourth of water section. Coefficient $n=0.0352$.

No. 234, W–9++, Hillsboro Ditch, Colorado. In general bad condition. Irregular gradient. Banks rough. Gravel channel scoured by current. Coefficient $n=0.0371$.

No. 238, SF–62**, lateral of Hyrum Canal, Utah. Partially overgrown with alfalfa. Strip of moss on each side occupied about one-fifth of channel. Bed of flat fragments of rock, up to 3 inches greatest dimension. Coefficient $n=0.0393$.

No. 242, SF–24**, canal of Brigham City Electric Light Co., Utah. Well-formed canal. Bed of medium-sized unpacked gravel. One-third of water section filled with long waving water plants. Coefficient $n=0.0424$.

No. 246, SF–46**, Brigham City Canal, Utah. About half full of horsetail moss. Such bed as exposed is gravel. Edges overgrown with cress and weeds. Coefficient $n=0.0499$.

No. 247, SF–53**, lateral of Thatcher Canal, Utah. About two-thirds filled with horse-tail moss. Such bed as exposed is sediment. Coefficient $n=0.0519$.

No. 248, SF–52**, lateral of Thatcher Canal, Utah. About three-fourths filled with moss. Bed as exposed is fine sediment. Coefficient $n=0.0529$.

COBBLE-BOTTOM DITCHES.

No. 250, W–13++, Beasley Ditch, Boulder, Colo. Channel of gravel on bottom with cobbles on the sides. On a slight curve with no vegetation in channel. General condition would be classed as good. Coefficient $n=0.0220$.

No. 256, SF–47**, Logan and Hyde Park Canal, Utah. Entire channel composed of loose coarse gravel up to hen's egg in size. Coefficient $n=0.0337$.

No. 257, SF–33**, lateral of Hyrum Canal, Utah. A case where water flows very slowly over a rough surface on steep grade. Bed composed of loose cobbles up to 3-inch size. Coefficient $n=0.0365$.

No. 258, SF–57**, lateral of Smithfield Canal, Utah. Canal on steep grade with bed composed of gravel and cobbles. Coefficient $n=0.0377$.

No. 260, SF–56**, lateral of Smithfield City Canal, Utah. Edges uneven. Bed of clean-washed gravel and cobbles. Coefficient $n=0.0423$.

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